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Lift Axles in Ready Mix Trucking

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Lift Axles in Ready Mix Trucking

by

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Dedication

Dedicated to my parents and my siblings

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Abstract

Lift Axles in Ready Mix Trucking

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Lift axles on single-unit commercial vehicles, referred to as Specialized Hauling Vehicles (SHVs) are being used today by various industries, allowing for heavier truck loads and compliance with state / federal laws. Certain industries – such as aggregate and hot mix, refuse, and ready mix – operate SHVs more frequently than other industries. The purpose of this Thesis research is to analyze the ready mix industry and understand the benefits and dis-benefits of operating SHVs as part of a company's truck fleet. In addition, the author seeks to gain an understanding of differences in state and federal laws, codes, and regulations regarding SHVs. Further, the research aims to understand the reasons ready mix companies choose to operate (or not operate) lift axles.

To achieve the objectives of this research, the author conducted a literature review, performed statistical analysis on ready mix truck sales data, studied SHV operation data in Texas, summarized lift axle regulations in the United States, analyzed previously conducted trade group surveys, and administered a survey to determine patterns and gain

information about lift axle use in the ready mix industry, with a focus on Texas and nine other peer states.

Sales data showed that the ten states in focus had an overall proportion of 32% of SHVs in the ready mix industry. In regulations, four of the states studied do not have specific lift axle laws. In these states, regulations applicable to lift axle weights are those applicable to general commercial vehicles based on the Federal Bridge Formula B, and state axle weight exemptions, if they exist. Some states have regulations controlling where the lift axle control mechanisms must be placed, while two states have regulations allowing trucks to lift axles during turns.

Analyzed surveys showed an SHV proportion in the ready mix industry around 60-70%. The author's survey corroborated this, with 64% of the responses from companies that operate SHVs. Analyzed survey data showed a growth trend in SHV configurations of about 1% per year. Reponses to the author's survey responses suggest companies select lift axles for the following reasons: to carry more weight and to be legal on highways with load ratings based on the Federal Bridge Formula.

All stakeholder contacts mentioned an upward trend in lift axle usage which was corroborated, although to different degrees, in the previously performed data collection efforts in Texas, analyzed surveys, and the author-administered survey.

Lift Axles in Ready Mix Trucking

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Chapter 1: Introduction

1.1 Background and Motivation

The ready mix concrete industry supplies a valuable construction product – ready mixed concrete – to the transportation, building sector, residential, and other construction markets (“About Concrete”, n.d.). A key component of ready mix is Portland cement, with 75% of the cement shipped in the United States consumed by the ready mix industry. Portland cement is an essential construction material, critical to the building and rebuilding of US infrastructure. The US is the third largest producer of cement, with annual production roughly around 97 million metric tons, according to the Portland Cement Association. The United States Geological Survey (USGS) estimates differently, with the annual production values around 85 million metric tons (USGS, 2019). Using production trends for Portland cement as a proxy for ready mix production, ready mix production is expected to continue increasing in the coming years, as the Portland Cement Association forecasts cement production to increase to 192 million metric tons by 2035 (Sullivan, 2009). The USGS data also supports this growth, albeit with different predictions. From 2015 to 2018, cement production saw an average growth of over 1 million metric tons per year (USGS, 2019). Looking at sales data for the ready-mixed concrete industry, this trend of growth is already visible, with a value of $27 billion in sales in 2005 (Syverson, 2008) and an estimated $35 billion in sales in 2019, (“About Concrete”, n.d.).

American Society for Testing and Materials International, specification, ASTM C94, states that the maximum time from introduction of mixing water at the ready mix plant to discharge of the ready mix is 90 minutes (ASTM International, 2019). Typically, ready mixed concrete is transported in a drum, or transit-mixer which contains ready mixed concrete that has been proportioned at the ready mix plant. However, a volumetric ready mix truck is of a different design and can mix concrete on site using water and dry ingredients including cement, aggregate and sand, stored in compartments in the truck mixing unit. The concrete is mixed on site using a metering system that controls the amount of each ingredient needed to produce the desired mix properties. A volumetric mixer is typically used for mixing concrete for sidewalks, curbs and rip rap or other non-structural applications. Both drum mixers and volumetric mixers can be manufactured or later modified as SHVs. A transit ready mix truck consists of a revolving drum that either combines cement, aggregate, and water to form ready mix, or keeps pre-mixed material agitated while in transit to the delivery site, to prevent the batch from segregating – that is to ensure the aggregate, sand and other materials remain thoroughly mixed. There are two primary types of transit mixers, front- or rear-discharge and many variations in how a ready mix truck can be configured including the number, position and types of axles.

SHVs are defined by the AASHTO *Manual for Bridge Evaluation* (AASHTO, 2011) as closely-spaced multi-axle single-unit trucks. More specifically, SHVs are generally short wheelbase multi-axle trucks used in the construction, waste management, bulk cargo, and commodities hauling industries. The Federal Highway Administration (FHWA) also refers to the AASHTO definition when describing SHVs. The FHWA clarifies and says “some SHVs are equipped with lift / drop axles” (Federal Highway Administration, 2013). However, this Thesis will restrict the definition of SHVs beyond the AASHTO and FHWA definitions, by only including multi-axle single-unit trucks which have one or more lift / drop axles, hereafter referred to as lift axles.

A lift axle is an axle that is mechanically raised or lowered. When the axle is lowered, tires are in contact with the pavement. The axle allows for an increase in the load capacity of the vehicle, as it bears some of the load from the vehicle and payload and changes the way these weights are distributed across the different axles. When not needed, the axle can be retracted so the tires are not in contact with the ground surface. Depending on the location the lift axle is placed on the truck, the methods used to lift and lower the axle, and other factors, these axles may be referred to as *liftable axles, lift axles*, *airlift axles*, or by specific names such as *booster axles*, *tag axles*, *pusher axles*, or *stinger axles*.

Usage of these axles presents state transportation officials with questions. For example, law enforcement officials are concerned about the possibility of drivers lowering lift axles on an overweight truck only when approaching a weight enforcement station (Sivakumar, Moses, Fu & Ghosn, 2007), thus misrepresenting the true impact to the transportation infrastructure. If this is a common occurrence, it could adversely affect the condition of the infrastructure, since overweight axles and vehicles can cause significant increase in consumption of pavements and bridges.

Adding to this ongoing nationwide discussion, the FHWA released a memorandum in November 2013 requiring each state to certify that it either does not permit operation of SHVs or conducts bridge force effects load rating analyses using standard AASHTO loads and applicable SHV load configurations (Federal Highway Administration, 2013).

1.2 Problem Statement

Most of the current research regarding SHVs focuses on their effects on infrastructure. However, this Thesis research will focus on the following:

1) What does collected data reveal about the current numbers, fleet distribution and use of ready mix SHVs?
2) How do different states regulate SHV operations through laws, code, and regulations?

3) What are factors that influence a ready mix company's decision to operate SHVs, or not, and what are the factors that guide this decision from company to company?

Understanding the answers to these questions can help planners, traffic, bridge and pavement engineers to better understand and forecast future growth in the number of SHVs operating within their jurisdiction. Further, changes over time can be better understood in the configurations of SHVs within a state, a region within the state, or along certain corridors within a state.

1.3 Scope of Thesis

The scope of the Thesis is limited to the above issues, and some limitations of the research are:

1) Though lift axles can be mounted to single-unit trucks, a truck tractor, or a trailer, this Thesis focuses on lift axles installed on single-unit trucks.

2) The Thesis will explore ready mix SHV and lift axle use, state laws, code, and regulations in Texas and nine other states including: California, Florida, Georgia, Illinois, Michigan, New York, North Carolina, Ohio, and Pennsylvania.

3) Although this Thesis reports findings beyond the ready mix industry – about SHVs in general - the primary focus of this Thesis is limited to the ready mix industry.

1.4 Research Objectives

The first objective of this Thesis is to gain a thorough understanding of current ready mix SHV operations. To inform this aim, the author performed a review of lift axle research, as well as statistical analyses of ready mix SHV operation data. The second objective of this Thesis is to compare how states vary in their truck laws, code, and regulations regarding ready mix SHVs. To inform this aim, the author analyzed legislation and state guidelines for Texas and nine peer states. The third and final objective of this Thesis is to document and explain the factors that motivate ready mix companies to operate SHVs (or not). To inform this final aim, the author performed statistical analyses on survey data from different sources, as well as interviewed and surveyed various ready mix trucking company representatives in the United States.

1.5 Methodology

The research approach employed by this Thesis is the following:

- Statistical analyses of SHV count data and survey data.
- Analysis of laws, codes, and regulations from Texas and nine peer states.
- Interviews and surveys of ready mix company representatives.

1.6 Organization of Thesis

The remainder of this Thesis is organized as follows: Chapter 2 presents a thorough literature review, describing types of lift axles, describing lift axle mechanisms and operations, and discussing possible advantages and disadvantages of lift axle usage. Chapter 3 presents data on SHV usage, including current configurations seen and lift axle laws. The chapter also discusses statistics of SHV usage in the US. Chapter 4 presents a discussion of analyses of lift axle regulations in 10 states across the United States. Chapter 5 discusses surveys and interviews of representatives of the ready mix industry. Finally, Chapter 6 summarizes results of the previous chapters and provides conclusions, as well as possible directions for future research.

Chapter 2: SHVs: A Literature Review

2.1 Specialized Hauling Vehicles

As stated in Chapter 1, an SHV is defined both by AASHTO (AASHTO, 2011) and FHWA (FHWA, 2013) as single-unit trucks with multiple axles that are closely spaced. As also mentioned before, this Thesis will restrict the definition of SHVs to only include multi-axle single-unit trucks which have one or more lift axles. A ready mix truck typically has three fixed axles, including a steer axle and a rear tandem axle. Lift axles are added either in front of (pusher) or behind (tag or booster) the tandem axle.

This chapter aims to describe SHVs by discussing the types, mechanism of operation, control mechanisms, and advantages / disadvantages of usage of lift axles. The following descriptions are applicable to lift axles in general, not specifically those on ready mix trucks.

2.2 Types of Lift Axles and How They Work

To fully understand lift axle usage in the ready mix industry, it is imperative to understand how lift axles function.

A lift axle is a truck axle that is designed to be raised from the ground when not in use. This is done to save tire wear during normal operations and to make steering around corners or sharp curves easier. Lift axles may be designed as non-steering, caster-steered or twin-steer. Caster-steered lift axles can track the turning movements of the truck to a limit, however trucks with multiple lift axles may scrape the tire contact areas on the pavement surface during a turn. This occurs when the turn radius is tighter than the steering radius of the axle and can cause uneven tire wear and may also damage the pavement surface. A twin-steer lift axle is linked to the fixed steering axle and can be distinguished from a caster steered axle since, when the driver turns the steering wheel, both the fixed steer axle and the twin-steer lift axle will turn; regardless if the truck is moving or not. However, a caster-steered axle is not linked to the truck steering wheel and will only turn when the truck starts moving and makes a turn; the caster steered axle simply follows the path of the truck.

When deployed, lift axles increase the number of tires in contact with the ground, and can change the axle loadings of the fixed axles, thus decreasing the load carried by each axle. Based on field tests with portable scales, even distribution of load between the tires on an axle might not be feasible due to the axle design, the pavement cross slope, the way in which the cargo was loaded, variations in the cargo compartment design, tare weight symmetry, and center of gravity. As an example, a ready mix drum has flights inside the drum for mixing or delivering the ready mix – the flights are thick metal plates, shaped in the form of a spiral, that vary in dimension along the length of the drum and can, therefore, vary the load on the fixed axles from side to side by 1,000 pounds or more depending on the drum position. Furthermore, the positioning of the flights can also affect the load of different axles (even within the same axle group) differently, such as affecting the load of the front axle of a tandem group more than the rear axle of the tandem group.

Distributing the load among fixed and lift axles may achieve compliance with weight-limit laws or simply increase the truck’s weight-carrying capabilities. When not needed, such as when the truck is empty after a delivery, the lift axles can be raised.

When describing lift axles and SHV axle configurations, the following terminology appears frequently in the literature and is important to understand:

- *Pusher axle* refers to a lift axle situated directly in front of a fixed axle group.
- *Tag axle* refers to a lift axle situated directly behind a fixed axle group.

- *Booster axle* (also known as a *stinger axle, trailing axle and flying tag axle*) refers to a lift axle that is positioned a significant distance behind the truck and lifts high above the frame of the vehicle when raised and is stowed upright against the rear of the truck.

The tires used on lift axles can also vary significantly in size from truck to truck. For SHVs with 2 or more lift pusher axles, the tires are generally smaller (lower profile) than the other tires on the truck, allowing the tires to be lifted further off the ground, lessening the possibility of the tire hitting the ground when driving on uneven surfaces (Smith, n.d.). However, lift axle systems on trucks with 4 or fewer total axles typically do not have low-profile tires. Also, there is variation within industries, such that dump and ready mix trucks typically employ low-profile tires on lift axles, while solid waste trucks typically do not. Figure 2-1 shows a lift axle (from one of the leading lift axle manufacturers Hendrickson International), while Figure 2-2 shows how one of these axles appear when raised. All figures from company catalogs, such as Figures 2-1 and Figure 2-2 below, were used by permission.

Figure 2-1. Hendrickson International Composilite TVR Lift Axle (Hendrickson International, 2014) (used by permission – Hendrickson International)

Figure 2-2. Four-axle ready mix truck [1S-2-1B[1]] with a booster lift axle (McNeilus, 2016) (used by permission – McNeilus)

[1] The designation [1S-*x*-*y*-*z*] (such as 1S-3L-2) such as in Table 3-1 and Figures 2-4 through 2-7 refers to an SHV configuration with *x, y, and z* indicating the number (and type) of axles behind the steering axle. For example, 1S-1L-2-1B is an SHV with five total axles, with a steering axle (S) in the front, one pusher lift axle (L) followed by a fixed tandem axle, and a booster (B) axle in the back. 'L' can refer to pusher axles or tag axles, depending on the positioning of the adjacent fixed axles.

Typically, the raising and lowering of these axles is done by employing either a hydraulic or an airbag system. Generally, the driver has the ability to raise and lower the axle (although this depends on the model of the lift axle system), as well as change the pressure in the air / hydraulic bags, leading to a change in the amount of load exerted on the lift axle itself. In Texas, the controls for raising / lowering axles are in the cab of the truck, while the controls for adjusting the load on the axles are outside of the cab, beyond the driver's reach during driving. In addition, depending on how the control mechanism is installed, each axle can be raised or lowered independently of other lift axles. Thus, it is not uncommon to see a six-axle truck with one or two of the lift axles up and one remaining down. There is also variety regarding which axle(s) are up or down as the truck travels down the road. This raises the question of how different combinations of lift axle positions affect braking or steering of a loaded truck. Further study is needed to document truck behavior under these conditions.

Numerous lift axle design variations exist due to different applications. As an example, a tie rod is part of the steering mechanism of a vehicle, which connects the idler arms and transmits force from the steering center link to the steering knuckle, causing the wheels to turn in unison. Lift axle manufacturers can place the tie rod in front of the axle or behind it, which can change the way the wheels turn. Vehicle wheel turns follow a geometric principle called the Ackermann Steering Principle, named after Rudolph Ackermann, who patented the principle in 1818. The principle describes the geometry that is applied to all vehicles (two- or four-wheel drive) to enable the correct turning angle of the steering wheels to be generated when negotiating a corner or a curve (Burnhill, 2009). The placement of the tie rod (front or back) affects the turning radii of the wheels, which can cause scuffing during turns. Tie rods in the front of the axle may be damaged if the truck is operating off-road and hits a large object, e.g. a large rock. Some manufacturers place the tie rod behind the axle or have designed tie rods that are made of shock-absorbent materials which can flex when it hits a rock or other debris.

Another important lift axle system consideration is ride height. Ride height is defined differently in different contexts. In the case of lift axles, it is defined as the amount of space between the center of a vehicle tire and the underside of the vehicle frame. Following the procedure shown by Hendrickson International, it is calculated by taking the loaded vehicle frame to ground measurement and subtracting the loaded tire radius of the selected lift axle tire.

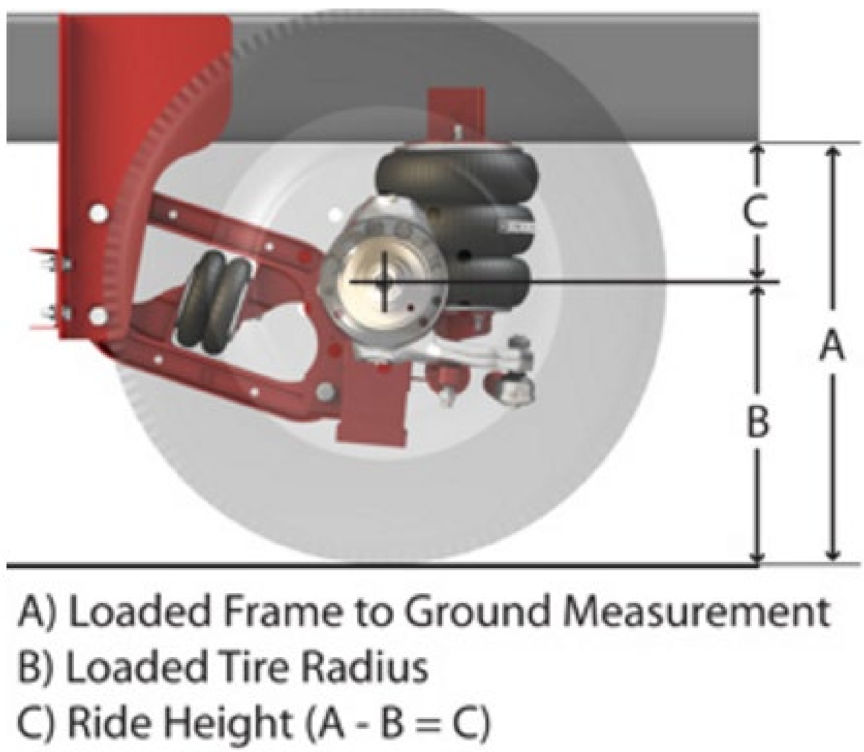


Figure 2-3. Hendrickson International Ride Height Measurement (Hendrickson International, n.d.) (used by permission – Hendrickson International)

Lowering a vehicle in any way lowers its center of gravity, and a low center of gravity helps make the vehicle pitch and roll less. From this perspective, there is a safety benefit to a low ride height. A lower ride height also provides aerodynamic benefits, increasing the truck's downforce without a significant increase in drag. However, a low truck ride height may have adverse effects. For lift axle vehicles, a lower ride height results in less physical space for raising the lift axle. This also increases the possibility of the truck damaging chassis components when driving on uneven road conditions, especially when off-road. Some lift axle manufacturers provide lift axle systems with adjustable ride heights to meet a variety of truck configurations.

Lift axles may be available preinstalled on a new truck based on specifications given to the manufacturer by the purchaser. Lift axles might also be retrofitted by an aftermarket company to a newly purchased truck, or when modifying a used truck. While the first type of truck is originally designed as an SHV, retrofitting lift axles to a new or used truck converts a truck to an SHV. Retrofitting a new or used dump truck to an SHV is more common though ready mix trucks might be retrofitted to an SHV as well. However, a problem that sometimes occurs with truck conversions is that the original truck's chassis may not have been designed to carry the additional loads imposed by additional axles. An article on Concrete Construction warned ready mix suppliers of the risks of adding a tag axle to a ready mix truck, stating that adding a lift axle may alter the weight distribution in unforeseen ways (Ward, 1994).

Table 2-1 shows a few of the available lift axle manufacturers currently in business and the number of lift axle options they have for sale on their website. The options vary based on load capacity, steerable / non-steerable, ride heights, and the other considerations mentioned above. It should also be noted that lift axles can also be modified once purchased, either by the manufacturer or by a third party, to fit an even more specific need.

Table 2-1. Lift Axle Options from Various Lift Axle Manufacturers

Lift Axle Manufacturer	# of Lift Axle Models on Sale (Website)	# of Steerable Models	# of Lightweight Models	# of Heavy-Duty Models
Hendrickson	22	11	3	8
Link Manufacturing	6	3	3	2
Reyco Granning	5	2	2	3
Ridewell	7	5	2	3
Silent Drive	23	8	6	2
Watson & Chalin	16	12	3	5

The above-mentioned options are for lift axles on the body of the truck, such as tag or pusher axles. The different types of lift axles seen on single-unit ready mix trucks are shown in Figures 2-4 through 2-7.

Figure 2-4. Five-axle, SU5, front discharge ready mix truck [1S-2L-2] with pusher axles (MyLittleSalesman, n.d.)

Figure 2-5. Four-axle truck [1S-2-1B] with one booster axle (McNeilus, 2017) (used by permission – McNeilus)

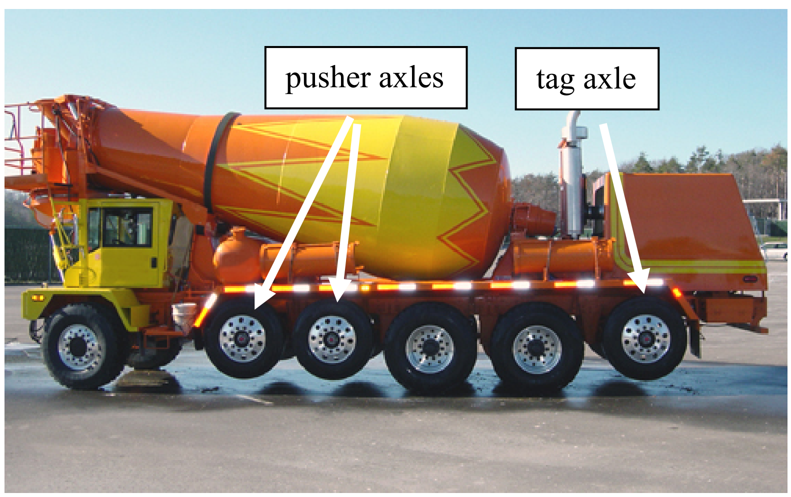


Figure 2-6. Six-axle truck [1S-2L-2-1L] with two pusher axles and tag axle (Seitz, 2004.)

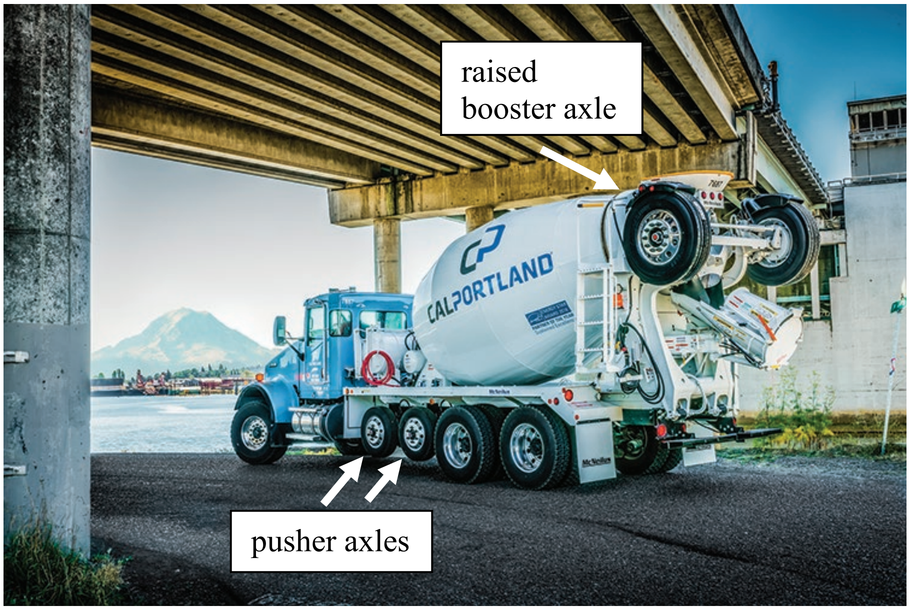


Figure 2-7. Six-axle truck [1S-2L-2-1B] with two pusher axles and retracted booster axle (McNeilus, 2017) (used by permission – McNeilus)

Lift axle options include steerable and non-steerable axles, as well as single steer or twin steer axles. Twin steer axles allow improved turn stability compared to single steer configurations, as the driver has control over more wheels. The main difference between steerable and non-steerable is that the caster-steered axle tracks the same path as the steering axle during turns. Therefore, if a turn isn't too tight, pavement scrubbing is not an issue. On the other hand, non-steerable axles do not turn and remain in line with the fixed rear axles, and thus its tires "will plow asphalt and scrub concrete, and will scuff tire tread and impose high lateral stress on wheels and chassis components" during turns (Berg, 2010). Therefore, to reduce both pavement and equipment damage, drivers raise non-steerable lift axles before a turn. However, some states do not allow this practice, as the truck is technically overloaded on the other axles during the turning maneuver. In such states where lifting during turns is not allowed or lift axle controls are mandated to be situated outside of the truck cab, steerable lift axles are the driver's only option for lift axles. The downsides to steerable axles, from the perspective of drivers, are higher equipment weight, costs, and maintenance needs, all due to the presence of more parts to incorporate steering ability. be referred to by different names elsewhere in industry / law enforcement.

2.3 Lift Axle Controls

The control systems for lift axles also present some levels of variation and customization. Generally, there are two types of controls which form a lift axle system: the controls that raise and lower the axles physically, and the controls that determine how much weight is loaded onto the axle. Many combinations are possible for the location and configuration of these two controls, and the combination seen in practice is determined by the laws of the state in which the trucking company operates. For example, some states restrict either type of control from being within reach of the driver during operation, i.e., while the vehicle is in motion. In such states, the controls are placed outside, on the body of the truck. Other states allow the raising / lowering control to be inside the cab (within the driver’s reach), but do not allow the controls for regulating weight to be inside. Some newer axle systems take all control away from the driver and are designed such that the lift axles automatically deploy themselves when needed, setting the weight for optimal performance, based on the total weight of the truck ("Mack targets tank fleets for new Load Logic 6x2 liftable pusher axle", 2015).

Another variation in the control system includes the mechanism for adjusting the weight carried by the lift axle. Some control systems regulate the weight in terms of pounds carried, using an adjustment knob and gauge to determine how much weight the lift axle will carry, while other mechanisms are calibrated according to other units. For example, a ready mix company interviewed for this research sets the load according to the volume of ready mix in their drums. The driver only needed to select the number of cubic yards of material being transported, and the control mechanism adjusted the lift axle air bag pressure accordingly.

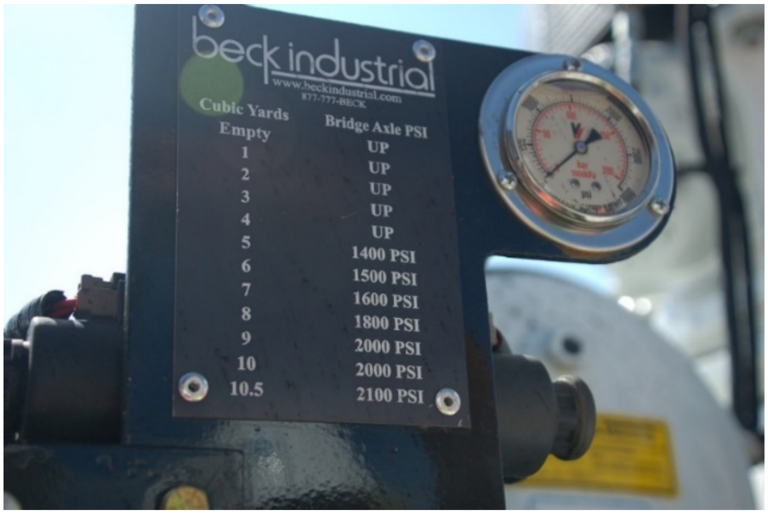


Figure 2-8. Lift axle air bag pressure versus cubic yards in drum (Murphy, 2016)

The following figures depict lift axle control systems photographed on a seven-axle 'superdump' dump truck.

Figure 2-9. Inside-cab controls for booster axle (Hasan, 2016)

Figure 2-10. Inside-cab controls for pusher axles (Hasan, 2016)

Figure 2-11. Outside-cab pressure gages / controls for pusher axles (Jiang, 2016)

Figure 2-12. Close-up of outside-cab pressure gage / control for pusher axle (Jiang, 2016)

Figure 2-13. Outside-cab pressure gage / control for booster axle (Jiang, 2016)

2.4 Lift Axle Advantages and Disadvantages

Generally, lift axles allow trucks to carry more weight by adding a load-bearing axle to the truck. Lift axles also provide truckers with more control over how weight is distributed amongst all axles, as well as the flexibility of adjusting the truck's configuration to fit the need of a particular operation. Not specific to the ready mix industry, but for lift axle trucks in general, replacing five-axle tractor-trailers with SHVs also might benefit operator safety, as SHVs are shorter and easier to operate (Muthumani & Shi, 2015). However, this might be offset by the fact that shorter, heavier SHVs will have a higher center of gravity, which will increase the chance of rollover crashes. Furthermore, a study conducted on semi-trailers with lift axles concluded that lifting axles on semi-trailers led to some fuel savings (ranging from 1.3% to 2.8% savings), although the study did not include single-unit trucks (Surcel & Bonsi, 2015). Some possible disadvantages identified include the following (Sivakumar, Moses, Fu & Ghosn, 2007):

- Lift axles, when deployed, reduce the turning capabilities of the truck and may cause tractor-trailers to jackknife on slippery roads. If axles are raised through the turn, the truck's stability is compromised, and the chance of rollover is increased.
- The proportion of the load carried by the lift axle is often controlled by the driver. This system introduces the opportunity for operator error, in which an axle or set of axles may carry too much or not enough of the load.
- Enforcing compliance with lift axle regulations is difficult. Lowering retractable axles when approaching a truck weight enforcement facility and then raising the lift axles after clearing the facility is not uncommon.

A 1991 *Transportation Research Record* study found that, although shippers benefit from lower transportation costs by using lift axles, there is a "solid technical basis for regulatory measures that would limit the application and use of liftable axles" (Billing, Nix, Boucher & Raney, 1991), primarily due to issues regarding weight compliance, roadway wear, bridge loading, and intrinsic truck safety issues.

One of these safety issues is braking force of a lift axle. If a lift axle is raised off the pavement, it cannot produce a braking force and increases the truck center of gravity. However, even when lowered, some lift axle systems have brakes that produce less braking force than steering axles or drive axle(s). A 1990 study conducted by the Northwestern University Traffic Institute on coefficient of friction in traffic accident reconstruction found (Fricke & Baker, 1990):

- All other factors being equal, the axle with the lightest load will lock first during braking. During skidding, there are no lateral friction forces available to prevent sliding of the tires due to curve super elevation or pavement cross slope. Anti-lock

Braking Systems (ABS) automatically compensate for differences in wheel loads, addressing this issue.

- All other factors being equal, the wheel with the least radius will lock first as brake pedal pressure is increased. This is because the maximum torque (rotational moment) of a wheel on a vehicle in motion is equal to the coefficient of friction of the tire on the road times the weight on the tire times the leverage (moment arm). The moment arm is the distance from the axle to the road - that is, the tire radius. With equal road friction, weight, and brake resistance to rotation, the wheel with the greatest moment arm can overcome brake resistance, while the wheel with the least moment arm cannot - Thus, with increasing but equal brake effort, the wheel with the least radius (moment arm) will be the first to start sliding.

Thus, even if the braking force for a lift axle is the same as for the fixed tandem axles, lift axle brakes will lock first, causing the tires to skid. This results in zero lateral force preventing the truck from sliding sideways. Thus, if all lift axles lock first, the tendency will be for the rear of the truck to slide in the direction of downward sloping pavement surface (due to pavement cross slope, or super elevation). However, this will only occur if the braking force supplied by the brakes on the lift axle are equivalent to the braking force of the fixed tandem axles.

A representative for a liftable axle manufacturer was interviewed about lift axles and asked for details regarding liftable axle braking capacities. The representative said: "Lift axles come in various weight capacities depending on what each state allows. Most common weight capacities are 8k, 13k and 20k lbs. Each of these has brakes matched to the axle's carrying capacity. Brake capacity is determined by the size of the brake shoe, thickness and material of the lining and stroke of the brake chamber. Timing of the brakes is determined by the brake valve. So, braking capacities match the carrying capacity of the axle, and vary from SHV to SHV".

The National Highway Traffic Safety Administration (NHTSA) requires the following stopping distances for loaded and unloaded single unit trucks, as shown in Table 2-2. For speeds ranging from 20 to 60 mph, the stopping distance for loaded single unit trucks ranges from 35 to 310 feet, and for unloaded single unit trucks, the stopping distance ranges from 38 to 335 feet. In addition, the Code of Federal Regulations (CFR) specifies the minimum deceleration rate for a single unit truck with service brake systems to be 9 feet per second per second when decelerating from 50 miles per hour to 15 miles per hour (highway braking), and 14 feet per second per second when decelerating from 20 miles per hour to stop (urban braking) (49 U.S.C. § 571.121).

Table 2-2. Stopping distances for single unit trucks for different vehicle speeds

Vehicle Speed (mph)	Stopping Distance for Loaded Single Unit Trucks (feet)	Stopping Distance for Unloaded Single Unit Trucks (feet)
20	35	38
25	54	59
30	78	84
35	106	114
40	138	149
45	175	189
50	216	233
55	261	281
60	310	335

A study was also conducted by Bedsworth et al. in which data from over 200 deceleration tests on commercial vehicles were analyzed (Bedsworth et al., 2013). This study used the average skid distance and the vehicle speed to calculate the vehicle's drag factor, f:

$f = s*s/(30*d)$

In the above equation, *s* is the speed of the vehicle in mph, and *d* is the vehicle's average skid distance. The drag factor times the acceleration due to gravity is equal to the deceleration rate of the vehicle. Of relevance to SHVs were data for ready mix trucks with lift axles and dump trucks with lift axles.

The Bedsworth data show drag factors based on skid distance, which should not be confused with the stopping distance in the NHTSA table. Stopping distance is the sum total of the braking distance (skid distance) and the distance travelled while the driver is perceiving-reacting to the braking situation. Therefore, the two values (stopping distances in Table 2-2 and drag factors based on skid distances in Table 2-3) cannot be directly compared.

Table 2-3 also shows the calculated deceleration rate, which can be related to the 9 ft/sec^2 value from the CFR. Since the Bedsworth experiments were done from starting speeds above 20 mph, the comparison can be made to the highway braking deceleration rate, although other differences exist that would make a direct comparison difficult, listed later in this section.

Table 2-3. Trucks in the Bedsworth study compared to regulated deceleration rate

Truck Type	SHV	Weight (lbs)	Test Run Number	Speed (mph)	Calculated Drag Factor	Calculated Deceleration Rate (ft/sec^2)
Concrete Mixer (1S-2L-2-1B)	Yes	51,900	1	28.6	0.32	10.3
			2	26.4	0.41	13.2
Three-axle Concrete Mixer	No	27,250	1	28.7	0.51	16.4
			2	35.8	0.56	18
Dump Truck (1S-3L-2)	Yes	50,200	1	25.3	0.44	14.2
			2	32.3	0.42	13.5
			3	30.4	0.49	15.8
Dump Truck (1S-1L-2)	Yes	65,900	1	27	0.6	19.3
			2	29.1	0.59	19
			3	26.2	0.59	19
Dump Truck with single rear axle	No	-	1	25.5	0.43	13.8
			2	40.1	0.68	21.9
Dump Truck (28')	No	26,500	1	28.2	0.56	18
			2	38	0.62	19.9
Dump Truck (25')	No	25,200	1	30	0.66	21.2
			2	34	0.48	15.4
			3	33	0.61	19.6
Dump Truck (22')	No	21,800	1	32	0.79	25.4
			2	34	0.72	23.2
			3	29	0.79	25.4

As can be seen above, three of the eight trucks were SHVs and all exhibited a deceleration rate above the minimum required rate. Of the three SHV trucks, one was a ready mix truck and two were dump trucks. These tests are of interest, but do not directly compare to the test methods used in developing the CFR criteria. The CFR tests were conducted to evaluate braking deceleration rates after multiple braking attempts that would have caused high brake temperatures. The Bedsworth tests did not include this condition.

The CFR tests were also likely conducted with new brakes and new tires, whereas the Bedsworth study was likely performed on trucks with brakes and tires that were worn to varying degrees. The trucks and number of axles in the two tests were also not the same. Further, the Bedsworth tests were performed on pavement whereas the CFR tests were in controlled laboratory conditions on a dynamometer. However, it is noted that every truck exhibited a deceleration rate above the 9 ft/s2 criteria established in CFR for trucks braking from speeds above 20 mph. It is also noted that multiple tests (with the same driver) yielded different results. These differences could be due to small differences from test to test related to the rate at which the driver depressed the brake pedal, air pressure build up in the braking system, slight differences in the exact test location, which might result in different pavement texture conditions and other factors. Furthermore, factors such as the disk brakes used also have a significant impact on brake distances. Therefore, more standardized research into SHV braking distances should be performed to understand safety issues further.

2.5 Ready Mix Truck Discharge Type

There are different variations of ready mix trucks that have been observed. One specific distinction is in the type of discharge mechanism, which can commonly be of two types: rear-discharge and front-discharge.

According to National Ready Mix Concrete Association's (NRMCA) annual surveys on fleet numbers and compositions, the proportion of rear discharge mixers (such as in Figure 2-7) is around 75%, with the remaining being front discharging (such as in Figure 2-6). Indeed, looking at the annual surveys over the years in Table 2-4, which is discussed in more detail in Chapter 5, it is clear that the proportion of rear discharge mixers has been significantly higher for the last decade (NRMCA, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017).

Table 2-4 Proportion of Rear-Front Discharge Mixers in Recent History (NRMCA)

Year	Front Discharge Vehicles (% of Total)	Rear Discharge Vehicles (% of Total)
2008	2,744 (19%)	11,835 (81%)
2010	2,383 (17%)	11,454 (83%)
2011	3,811 (25%)	11,497 (75%)
2012	2,249 (18%)	10,200 (82%)
2013	1,792 (17%)	8,797 (83%)
2014	3,946 (26%)	11,340 (74%)
2015	2,721 (17%)	13,563 (83%)
2016	2,164 (14%)	12,919 (86%)
2017	3,074 (19%)	13,472 (81%)

The main differences between the two types of trucks are the mechanisms for discharging ready mix at the delivery site, speed of operations, and capital and operational costs.

As the name suggests, a rear-discharge mixer truck discharges ready mix through a chute in the back of the vehicle, while a front-discharge mixer truck discharges through a chute located in the front of the truck, in front of the driver. For both of these types of trucks, the ready mix material is stored (and mixed) in large drums. The drum has two sets of one-piece, formed fins which make up the flights to both mix and elevate. The fins are placed opposite of each other, running the entire length of the drum. To mix, the drum is generally rotated by hydrostatic transmission power from the truck engine. The rotation of the drum is controlled by the driver with controls inside the cab (Kimble Mixer Company, 2014). The driver can control the direction of the rotation, which in turn changes the direction of the mix's flow (mix or discharge). At the discharge site, for a rear-discharge vehicle, the driver must back into the spot where delivery will occur. Typically, a separate employee, solely in charge of handling the chute, positions the discharge chute to accurately deliver the mix where needed. This employee is in charge of adding chutes to reach further distances if needed, and of manually moving the chutes left and right to ensure proper delivery. For a front-discharge mixer truck, the driver drives up to the delivery spot and, using chute controls from inside the cab, positions the chutes properly. Then, typically using a joystick trigger inside the cab, the driver can discharge the ready mix into place (Terex, n.d.).

Given the relative ease for a front-discharge mixer truck's maneuvering at the delivery site – drive up to the delivery spot instead of back into it – front-discharge mixers are generally faster to operate. Companies that sell front-discharge mixers claim that the increased speed of operations can lead to the possibility of making an extra delivery per day, which can lead to significant profits.

Another cost which front-discharge mixers can eliminate is an additional employee required to handle the chutes on a rear discharge mixer. This makes it possible for front-discharge mixer truck operators to manage with fewer employees.

However, according to an executive for a company that manufactures front-discharge mixer trucks, the front-discharge mixer trucks are more expensive to buy, costing roughly 15-18% more than the more common rear-discharge mixer trucks ("All about front discharge mixers", 2010). However, the executive states front discharge mixer trucks have a longer life cycle, as well as the previously mentioned speedier operations – and thus profit – so the cost difference isn't just the comparison of two simple numbers.

According to an executive at another ready mix trucking company, Ernst Concrete, rear-discharge mixer trucks are better-suited for higher-volume pours, such as building and roadway construction in big cities, whereas front-discharge mixer trucks are more suited to smaller, residential projects ("All about front discharge mixers", 2010). He also says rear-discharge mixer trucks have a higher chance of rollover, making front-discharge mixer trucks safer to operate.

This chapter provided an in-depth understanding of what lift axles are. The section described how their mechanism operates, some significant differences between the many types of lift axles available, how control systems work, and advantages and disadvantages of lift axles.

The next chapter discusses current SHV operations, with regards to types of SHVs commonly seen and other information about their current operations. Most of this information is focused on Texas, as a result of other research this author has been a part of, including the UT-CTR study mentioned in this chapter. The chapter also discusses statistics of SHV usage in the US.

Chapter 3: Current SHV Operations

The focus of this chapter is to evaluate SHV operations in Texas and nine peer states. The chapter begins with a discussion of different SHV truck configurations and the factors that influence them. Next, some results from lift axle research in Texas are discussed. Extra-Thesis research conducted by the author is discussed, as well as two surveys, completed by a scientific agency and an industry advocacy group.

3.1 Lift Axle Truck Configurations

SHVs operate with a variety of lift axle positions and types depending on the type of truck, desired load capacity, and state / federal laws. The laws that regulate configurations are detailed later in this chapter. The primary federal law that governs SHVs at the federal level is the Federal Bridge Formula (FBF), with some state laws adding size / weight restrictions for certain areas or roadway facilities. The SHV configurations that operate in a state are those that adhere to both federal and state regulations of that state.

Table 3-1 provides some examples of SHV truck configurations. The table, while covering many commonly seen configurations, may not be a comprehensive list of all possibilities.

Table 3-1. Example SHV Configuration Table Using Configuration Codes

Config Code	Description	SHV
1S-1L-2	1 Steering Axle, 1 Lift Axle (Pusher), 2 Fixed Axles (Tandem)	SU4
1S-2-1L	1 Steering Axle, 2 Fixed Axles (Tandem), 1 Lift Axle (Tag)	SU4
1S-2-1B	1 Steering Axle, 2 Fixed Axles (Tandem), 1 Lift Axle (Booster)	SU4
1S-2L-2	1 Steering Axle, 2 Lift Axles (Pusher), 2 Fixed Axles (Tandem)	SU5
1S-1L-2-1B	1 Steering Axle, 1 Lift Axle (Pusher) 2 Fixed Axles (Tandem), 1 Lift Axle (Booster)	SU5
1S-1L-2-1L	1 Steering Axle, 1 Lift Axle (Pusher) 2 Fixed Axles (Tandem), 1 Lift Axle (Tag)	SU5
1S-1L-2-1L-1B	1 Steering Axle, 1 Lift Axle (Pusher) 2 Fixed Axles (Tandem), 1 Lift Axle (Tag), 1 Lift Axle (Booster)	SU6
1S-3L-2	1 Steering Axle, 3 Lift Axles (Pusher), 2 Fixed Axles (Tandem)	SU6
1S-2L-2-1B	1 Steering Axle, 2 Lift Axles (Pusher) 2 Fixed Axles (Tandem), 1 Lift Axle (Booster)	SU6
1S-3L-2-1B	1 Steering Axle, 3 Lift Axles (Pusher), 2 Fixed Axles (Tandem), 1 Lift Axle (Booster)	SU7

The terms, configuration names, and configuration codes used in this Thesis may be referred to by different names elsewhere in industry / law enforcement.

3.2 Ready Mix Axle Configurations

There are numerous possible variations of how the axles on a commercial truck can be configured, and this fact remains true for ready mix trucks. These differences are based on the differences in operations, e.g. adding a pusher axle may increase the truck's legal gross vehicle weight, which will allow the truck to carry more cargo overall. However, the extra added axle will add some weight of its own, so there may or may not be an overall benefit, purely based on weight. There are also length requirements that come into play when determining how much a truck can carry legally, so the truck's increase in carrying capacity may also be determined by whether or not the truck frame is long enough to allow it based on federal laws and state statutes (Nadolny, 1994). Adding an additional axle may also change the maneuverability of the truck, especially during turns. The following photos depict the wide variety in ready mix truck axle configurations including both non-SHV and SHV trucks. These photos do not represent all possible configurations.

2-Axle Ready Mix Truck Configurations

A ready mix truck with only two axles does not have the option for much variability, since one of the axles must be the steering axle, and the other fixed. An example of such a truck is shown in Figure 3-1.

Figure 3-1. 2-Axle Rear Discharge Truck [1S-1] in Pennsylvania
(CommercialTruckTrader, n.d.)

3-Axle Ready Mix Truck Configurations

One of the most common ready mix truck axle configurations are 3-Axle configurations. Similar to 2-Axle configurations, there is not much room for variability. However, the truck can be rear discharge or forward discharge, and examples of these are shown in Figures 3-2 and 3-3.

Figure 3-2. 3-Axle Rear Discharge Truck [1S-2] (Kimble Mixer Company, n.d.) (used by permission – Kimble Mixer Company)

Figure 3-3. 3-Axle Front Discharge Truck [1S-2] in Tennessee (CommercialTruckTrader, n.d.)

4-Axle Ready Mix Truck Configurations

Another common set of axle configurations seen in industry consists of variations of 4-Axle trucks. Beyond the rear discharge vs. front discharge variation, at least one of the four axles can be a lift axle, of varying types in varying positions. Some examples of commonly seen variations are shown in Figures 3-4 through 3-8.

Figure 3-4. 4-Axle Front Discharge Truck, Twin Steer (1S-1L/S-2) in New York (CommercialTruckTrader, n.d.)

The above figure shows a rear discharge truck, where the second steer axle may or may not be a lift axle, hence the configuration code could be L or S.

Figure 3-5. 4-Axle Front Discharge Truck with Pusher Axle [1S-1L-2] in Virginia (CommercialTruckTrader, n.d.)

Figure 3-6. 4-Axle Rear Discharge Truck with Tag Axle [1S-2-1L] in Arkansas’ (CommercialTruckTrader, n.d.)

Figure 3-7. 4-Axle Rear Discharge Truck with low profile tire Pusher Axle [1S-1L-2] in Tennessee (CommercialTruckTrader, n.d.)

Figure 3-8. 4-Axle Rear Discharge truck with Booster Axle [1S-2-1B] in Texas (CommercialTruckTrader, n.d.)

5-Axle Ready Mix Truck Configurations

Although five axles allow for more variation than a four axle, with one more potential fixed or lift axle in varying positions and varying types, a large share of the configurations seen in practice are composed of two specific configurations. Both are shown in Figures 3-9 and 3-10.

Figure 3-9. 5-Axle Rear Discharge Truck with Pusher and Booster Axle [1S-1L-2-1B] in Minnesota (CommercialTruckTrader, n.d.)

Figure 3-10. 5-Axle Front Discharge Truck with Pusher and Tag Axle [1S-1L-2-1L] (Terex, n.d.)

6-Axle Ready Mix Truck Configurations

Ready mix truck configurations with six axles are not very common. However, two variations are seen, and are shown in Figures 3-11 and 3-12.

Figure 3-11. 6-Axle Rear Discharge Truck with Pusher Axles and Booster Axle [1S-2L-2-1B] in Minnesota (TruckPaper, n.d.)

Figure 3-12. 6-Axle Front Discharge Truck with Pusher Axles and Booster Axle [1S-2L-2-1B] in Utah (CommercialTruckTrader, n.d.)

7-Axle Ready Mix Truck Configurations

7-Axle trucks exist in the ready mix industry, with two possible configurations shown in Figures 3-13 and 3-14.

Figure 3-13. 7-Axle Rear Discharge Truck with Three Pusher Axles and Booster Axle [1S-3L-2-1B] (McNeilus, 2017) (used by permission – McNeilus)

Figure 3-14. 7-Axle Front Discharge Truck with Three Pusher Axles and Tag Axle [1S-3L-2-1L] (Courtney, n.d.)

3.3 LIFT AXLE RESEARCH IN TEXAS

Texas does allow operation of SHVs, and the number and range of actual gross vehicle weights (GVWs), axle weights, axle configurations, and spacing of SHVs in Texas has been researched (Walton et. al, 2017; Walton et. al, 2016). The author participated in the cited studies including collection of field data to determine where SHVs operate in Texas; the numbers and types of SHV configurations; and axle loads, axle spacing and Gross Vehicle Weights. Other aims were to evaluate the deterioration (consumption) rates for SHVs on pavements and bridges, evaluate safety considerations of SHVs, and prepare policy suggestions to manage SHV operations and load posting sign layouts for the Texas Manual on Uniform Traffic Control Devices (TMUTCD). The project was in response to the 2013 FHWA memo requiring each State DOT to investigate the SHV configurations operating in their state and to confirm that the AASHTO Manual for Bridge Evaluation contained SHV load configuration templates that represented the SHV fleet in that state. Further, based on the evaluation, if a state operated SHV configurations not represented by the AASHTO Manual on Bridge Evaluation SHV load diagrams, the state was to develop a new loading diagram for these SHV configuration(s) for further evaluation by FHWA and the State DOT, ensuring these loading diagrams envelope the applicable AASHTO developed diagrams.

The data used in the 2017 study came from five different sources:

1) Truck Sales data: the research team searched through and analyzed various sales databases in Texas to obtain counts for SHVs that were for sale. Over 1,500 trucks were counted and analyzed.

2) Site visits: the research team determined industries that were more likely to have SHVs in their fleets – dump trucks, ready mix trucks, etc. – and visited sites for these industries to obtain manual counts of trucks entering and leaving the facility, categorizing them as either SHV or non-SHV including the truck configurations. Over 3,250 trucks were counted and documented.

3) Route data: the research team collected visual observations of trucks and truck configurations during trips from Austin to Houston, San Antonio, Wichita Falls, Waco, and Marble Falls. These trips included counts passing through other cities and towns including Dallas, Ft. Worth, Mineral Wells and many others. Over 32,000 trucks were counted using this method.

4) Video data: 24-hour video feeds obtained from TxDOT were analyzed at different points in the state to count and categorize trucks. Over 20,000 trucks were counted this way.

5) Repeated trips on FM 1431, IH 35, FM 973: the research team travelled 87 times along the same route, in both directions, on different days of the week, and different times

of the day, over several months. During these travels, almost 21,000 trucks were counted and described.

6) Department of Public Safety Weight Enforcement Data and Weigh-In-Motion Data: the research team received over 292,000 records from the DPS Weight Enforcement team, as well as over 205 million records from 36 WIM stations across Texas. For both types of data, around 1% of the data were determined to be SHVs.

One result of this data was a synthesis of axle weight and axle spacing records for SHVs in Texas, which uses the weight data listed in item 6) described above. Table 3-2 (DPS) and 3-3 (WIM) show examples of the weight data analysis data results. Due to a lack of ready mix trucks in the DPS data, the example shown in Table 3-2 is for a five-axle dump truck with two lift axles (1S-2L-2). Table 3-3 shows axle spacing data for various SHVs seen in Texas, from Texas Department of Transportation Weigh-in-Motion (WIM) data. The WIM data did not contain any information about the type of truck.

Table 3-2. SHV axle weight distributions for five-axle 1S-2L-2 lift axle dump trucks (TX DPS weight data)

Percentile Weight (%)	Axle-1	Axle-2	Axle-3	Axle-4	Axle-5	GVW
5	14715	6919	6828	15994	15994	60450
25	15544	7309	7213	16895	16895	63850
50	16214	7624	7524	17624	17624	66610
Average	**16456**	**7738**	**7636**	**17887**	**17887**	**67600**
75	17455	8207	8100	18972	18972	71700
95	19157	9008	8890	20823	20823	78700

In Table 3-2, the Percentile Weight column shows, for this particular SHV configuration, the axle weights for the 5th, 25th 50th, average, 75th and 95th percentile truck axle and GVW weights. Thus, at the 25th percentile, 25 % of the trucks had axle weights and a GVW weight at or below these values. The calculated average weights are shown in red. The lift axles, axles ‘2’ and ‘3’ above, show that the average weights on the lift axles of this type of truck are slightly below 8,000 lbs. The average axle loads for the 1S-2L-2 configuration are shown to be 16,456 lbs for the steering axle, 7,738 lbs for lift axle 1, 7,636 lbs for lift axle 2, 17,887 lbs for fixed tandem axle 1 and 17,887 lbs for fixed tandem axle 2.

Table 3-3. SHV axle spacing data for various configurations in Texas (WIM weight data)

Configuration	No. Axles	Sp.1-2(ft)	Sp.2-3(ft)	Sp.3-4(ft)	Sp.4-5(ft)	Sp.5-6(ft)	Sp.6-7(ft)	Spacing Total(ft)
1S-1L-2	4	12.7	4.3	4.4	0	0	0	21.4
1S-2-1B	4	12.5	4.4	10.1	0	0	0	27.0
1S-2L-2	**5**	**11.3**	**4.1**	**4.1**	**4.4**	**0**	**0**	**23.9**
1S-1L-2-1B	5	13.4	4.2	4.5	10.9	0	0	33.0
1S-3L-2	6	11.1	3.8	3.8	3.8	4.5	0	26.9
1S-2L-2-1B	6	10.4	3.9	4.2	4.4	11.8	0	34.7
1S-3L-2-1B	7	8.7	3.5	3.5	3.6	4.4	11.7	35.4

Table 3-3 indicates the average axle spacings based on WIM data. The axle spacings are taken from center of axle to center of axle. For the configuration shown in Table 3-2 – 1S-2L-2 – the data show that the typical distance between lift axles is around 4’. Another notable measurement based on the spacing is the outer bridge length, defined as the distance from the center of the steer axle to the center of the rearmost tandem axle is 23.9’ in this example. The spacing above is shown in Figure 3-15, with a sample dump truck. It is interesting to note that as the number of lift axles increase, such as in the last configuration of the table, the spacing reduces to about 3.5’.

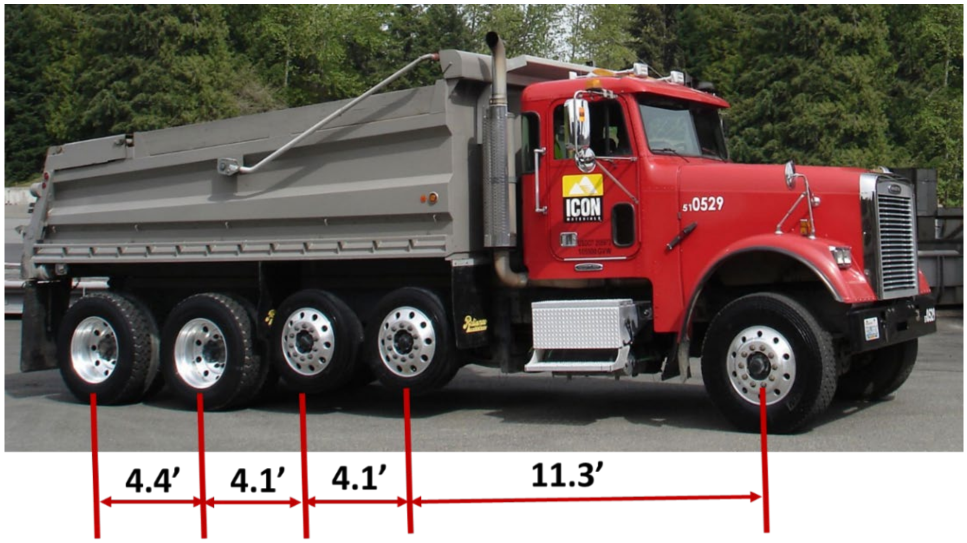
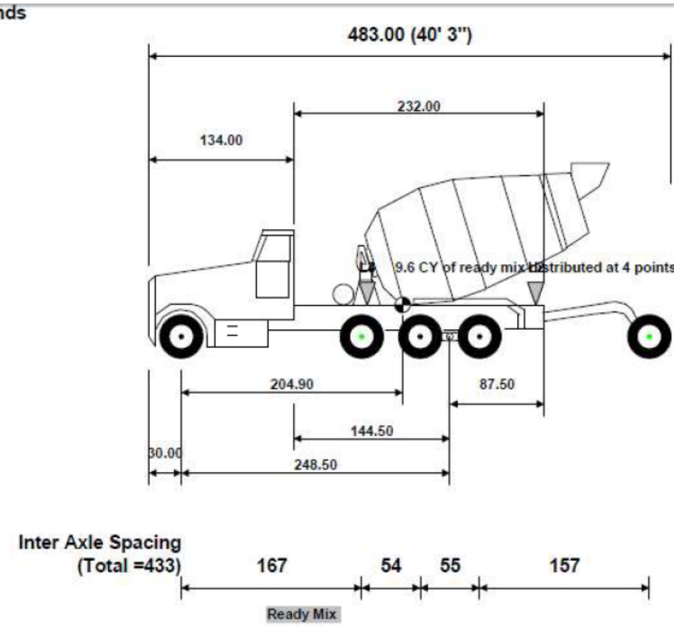


Figure 3-15. 5-Axle Dump Truck with Two Pusher Axles [1S-2L-2]

The author participated in a study to evaluate 5 SHV ready mix truck configurations specified in proposed legislation (Walton et. al, 2016). As part of the study, the researchers analyzed various ready mix truck configurations and also visited a ready mix plant to weigh and measure a ready mix truck with lift axles in loaded and unloaded conditions. The researchers used Load Xpert™ software to analyze ready mix truck configurations based on truck measurements and axle spacing information. An example Load Xpert™ analysis sheet is shown in Figures 3-16 and 3-17.

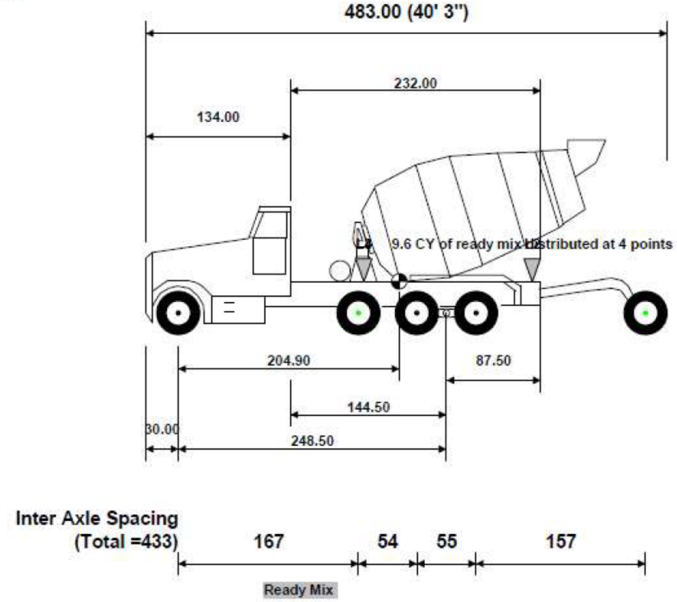
All lengths in inches and weights in pounds | Printout of Load Xpert software



Axle Loads:	#1 (lb)	#3 (lb)	#2 (lb)	#4 (lb)	Total (lb)
Tare:	9022	0	24978	0	34000
Accessories:	0	0	0	0	0
Payload:	10912	3300	8788	12000	35000
Total:	19934	3300	33766	12000	69000
Desired/(GVW)*:	U.S. Bridge Formula				-
GAWR/(GVWR*):	20000	8000	34000	12000	(70500*)

Figure 3-16. Load Xpert™ Analysis Page for 5-Axle Ready Mix Truck [1S-3-1B] Part 1 (Walton et. al, 2016)

All lengths in inches and weights in pounds | Printout of Load Xpert software



Axle Loads:	#1 (lb)	#3 (lb)	#2 (lb)	#4 (lb)	Total (lb)
Tare:	9022	0	24978	0	34000
Accessories:	0	0	0	0	0
Payload:	10912	3300	8788	12000	35000
Total:	19934	3300	33766	12000	69000
Desired/(GVW)*:	U.S. Bridge Formula				-
GAWR/(GVWR*):	20000	8000	34000	12000	(70500*)

Figure 3-17. Load Xpert™ Analysis Page for 5-Axle Ready Mix Truck [1S-3-1B] Part 2 (Walton et. al, 2016)

This analysis provided interesting insights regarding 3-axle ready mix trucks, which are authorized (without extra permits) under Texas Transportation Code Title 7 Section 622.011 to be operated at 23,000 lbs on the steering axle and 46,000 lbs on the tandem axle. This is due to a state exemption, which does not apply on interstate routes. However, the Load Xpert™ analysis showed that it was not feasible to carry 23,000 lbs on the steering axle without exceeding the tandem axle weight limit of 46,000 lbs. A Texas Department of Motor Vehicles Ready Mix Concrete Truck permit is available for purchase by 3-axle ready mix truck operators that permits 10% axle weight tolerances of 25,300 lbs on the steer axle and 50,600 lbs on the rear tandem though the allowable GVW of 69,000 lbs cannot be exceeded (TxDMV, 2019). In this way, a ready mix truck can achieve the maximum allowable 69,000 lbs GVW under state statutes. The Ready Mix Truck 10% axle weight tolerance permit does not authorize operation of a ready mix truck at this weight limit on the Interstate highway system; though operation on IH frontage roads is permitted.

The research team members were invited to weigh an empty and a loaded ready mix truck at a plant yard. Before the weighing process, the research team members were given the opportunity to take a TxDPS Weight Enforcement Training class to observe how HAENNI WL-101 weight scales are to be used when weighing a truck. This includes using a set of pieces of plywood for placement under tires that were not being weighed, referred to as blanks. During the weighing process, the research team measured an SU5 ready mix truck both empty and loaded using two HAENNI WL-101 portable weight scales, identical to the ones used by TxDPS, as well as using plywood blanks. The team learned that the measured weights varied from one side of the truck to the other due to the positions of the fins (flights) inside the ready mix drum. This was noticed in both the loaded and unloaded conditions but raises the potential for perceived weight violations when the truck is loaded. During the measurement process, the mixing drum was stationary, as the research team was allowed to measure a truck with a ‘calibration mix’ inside, i.e. a mixture of aggregate, sand, and water – no cement. Also, when the booster axle was lowered onto the ground and adjusted to an axle load of 12,000 lbs, the weight on the steering axle and the pusher lift axle increased, and weight was taken off the fixed tandem axle. This illustrates an important point about the usage of lift axles – their use can redistribute load along the truck, in ways that may not be readily apparent or intuitive.

3.4 SHVs in Texas – UT-CTR Statistics

Based on data collected by UT-CTR in Texas, the most common SHV operational types are dump trucks, ready mix trucks, and refuse trucks. It was also found that the building materials industry also operates SHV flatbed trucks that have a small crane or knuckle boom to load or unload shingles, lumber or other materials, such as the one shown below in Figure 3-18.

Figure 3-18. 4-Axle Flat Bed Truck with Knuckle Boom Pallet Fork Lift [1S-1L-2] (CTR, 2017)

However, at this time, building materials trucks represent a small fraction of all SHVs observed in Texas. This observation was determined from truck count data in the cities of Austin, San Marcos, Waco, Wichita Falls, Houston and San Antonio, and on roads connecting these cities (referred to as 'route data'). In addition, truck route data was obtained from TxDOT video traffic data collection sites at locations in various regions of Texas. Route truck traffic data were collected during trips within cities and between cities by creating a voice recording identifying types and configurations of all trucks observed moving along the route. Truck type was described such as 5-axle flatbed loaded with building materials, SU5 dump truck with 2 pusher axles in the up position, 6-axle unit with 3-axle tractor and twin 28-1/2' trailers (double bottom unit) FedEx Truck. When possible, the name of the company operating the truck was recorded for later reference. This data collection process helped ensure that no trucks were double-counted, since it was infeasible that the same truck would pass by the observer a second time during recording. These data were later transcribed to a spreadsheet and to a central database. In this way, a total of 53,519 trucks were counted, which included 5,693 single-unit trucks and 968 SHVs (1.8% of all trucks and 17% of single-unit trucks). Additional truck operation type data were collected along a single route in Austin and Cedar Park, Texas, which included FM-1431 from Anderson Mill Rd. to IH-35, then Southbound to FM-973 and the reverse route from FM 973 to FM 1431 at Anderson Mill Road. During each data collection trip, truck data were collected in both directions though a greater number of trucks were observed in the opposite direction of travel. This was due to the fact that trucks moving in the same direction as the observer were moving at the same speed and thus were overtaken infrequently. However, trucks passing by in the opposing lane were effectively moving at the combined speed of the truck and the observer vehicle. Data collection was performed on different days of the week and at different times of the day based on the Nielson Audio day parts definitions of Overnight (12 AM – 6AM), Morning (6AM – 10AM), Midday (10AM – 3PM), Afternoon (3PM – 7PM) and Evening (7PM to midnight). In this way, data for an additional 20,924 trucks were collected, including 8,906 single-unit trucks and 2,406 SHVs (11.5% of all trucks and 27% of single-unit trucks). The author is aware that trucks, including SHVs, could potentially be double counted using this method; however, the information provided a means for determining the number of SHV truck trips along a route that included two quarries, a concrete casting yard, two ready mix plants and two large landfills. Thus, this information helped the author understand SHV operations within a city along a route expected to have high numbers of SHVs due to the industries located along the route.

In addition to the route and repeat trip data collection counts, a team of researchers, including the author, collected fixed-site truck count data at quarries, ready mix plants, hot mix plants, landfills and other locations expected to be serviced by SHVs. From this method of data collection, a total of 58 company sites were visited across Texas, and a total of 3,367 trucks were counted, which included 598 SHVs (17.8% of all trucks). The researchers worked to reduce the possibility of double counting by keeping track of the registered TxDMV / USDOT number printed on the side of the truck, but this was not always feasible, especially when many trucks entered / left the facility within a short period of time. Thus, when the same truck was seen a second time, it was not counted in the total truck count for that location. Using this method, the data collection time period at a site was fixed at 2 hours, since repeat trips by the same trucks increased at and beyond 2 hours.

Based on field data collection, industries that operate relatively few SHVs in Texas include truck mounted cranes, petroleum industry, agricultural and farming industry, and fuel tankers. The authors of the UT-CTR study had previously expected that the petroleum industry would operate a larger number of SHVs as winch trucks, saltwater vacuum trucks, oil field work over rigs and other specialized units. However, relatively few of these trucks were observed to be SHVs. Oil well fracturing (fracking) operations in the various Texas shale plays were diminished during the course of the study which may have affected the number of oil field trucks including SHV oil field equipment that was observed.

Truck registration data from the Texas Department of Motor Vehicles – Vehicle Titles and Registration Section were analyzed to determine the counties in Texas with the highest number of registered dump, ready mix, and refuse trucks. These were determined to be Bell, Bexar, Brazoria, Collin, Comal, Dallas, Denton, Ector, El Paso, Fort Bend, Harris, Hidalgo, Lubbock, McLennan, Montgomery, Nueces, Potter, Tarrant, Travis, and Williamson counties. ArcGIS was used to visualize the counties with highest number of registered dump, ready mix, and refuse truck registrations with the TxDOT district boundaries in the state. The map, shown in Figure 3-19, also shows the location of three types of data collected.

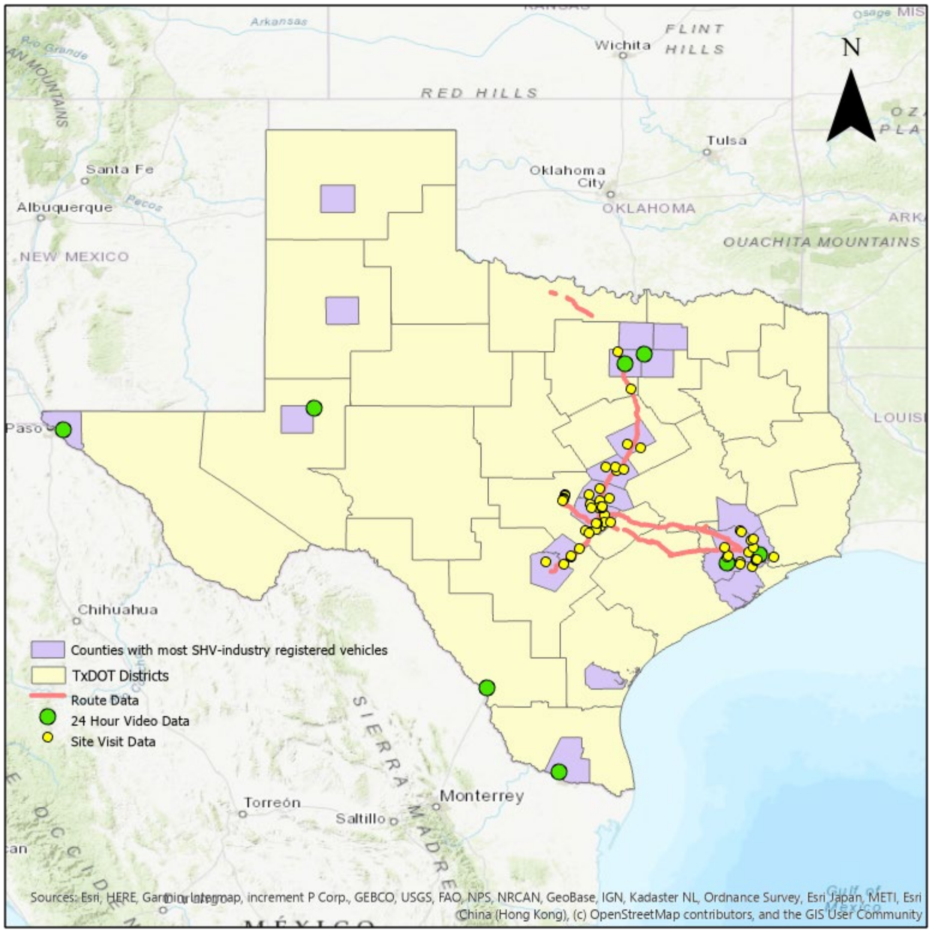


Figure 3-19. Texas map with dump / ready mix / refuse truck registrations over TxDOT District boundaries

One determination from the map is that there appears to be a similarity between metropolitan and urban boundaries, and the counties with the greatest number of industries that use SHVs. This is consistent with the fact that garbage trucks, dump trucks and ready mix trucks tend to operate within a maximum radius from the material plant (dump, ready mix) or landfill (garbage) to minimize travel times / distances. In addition, as previously mentioned, ready mix is considered a perishable product which must be delivered to the job site within a fixed time limit – usually 60 to 90 minutes – to ensure the mix is acceptable. Thus, ready mix truck operators tend to consider travel time, rather than travel distance when planning delivery routes.

The truck operation type field data and the TxDMV registration data also provided the means for calculating the estimated number of each configuration type for dump, ready mix, refuse, building materials and other type trucks. It should be noted that in Texas, truck registration data do not include the number of truck axles or types of axles. Thus, a registered dump truck might be a tractor-dump trailer, a three-axle single-unit dump or a type of SHV.

The truck sample sizes were sufficient for dump, ready mix, refuse, fuel tanker and flatbed trucks to estimate the number of five-axle combination units, three-axle single-unit and SHV configurations for these truck types with a 95% Confidence Level +/- varying percentages of margin of error (2% for dump trucks, 4% for ready mix trucks, and 3% for refuse trucks.

Table 3-4 shows the number of registered trucks, observed trucks and estimated number of truck types based on statistical sampling methods. This table was created utilizing data types 3 and 4 mentioned previously in this Thesis, i.e. Route Data and Video Data. For clarity, the SU3 configuration shown in the following tables describe a 3-axle truck with one lift axle between a steering axle and a rear fixed axle.

Table 3-4. Estimated numbers of trucks by truck type and configuration

Truck Type	Statewide Total Number	Percentage Observed						Statewide Number of Trucks - Estimated					
		SU3	SU4	SU5	SU6	SU7	Non-SHV	SU3	SU4	SU5	SU6	SU7	Non-SHV
Dump Truck	71,172	0.1	10.4	3.5	2.6	2.5	80.9	37	7,425	2,475	1,875	1,800	57,560
Garbage / Recycle	9,275	1.6	12.2	1.4	-	-	84.8	151	1,129	132	-	-	7,864
Ready Mix	9,155	-	7.7	5.0	6.6	-	80.7	-	702	460	605	-	7,387
Agriculture	7,284	-	-	-	-	-	100.0	-	-	-	-	-	7,284
Other	8,907	-	12.9	0.4	-	-	86.7	-	1,151	38	-	-	7,718
Total	105,793	0.3	10.7	2.9	2.3	1.5	82.4	108	4,093	1,133	904	578	87,813

3.5 SHVs in Texas – Sales Data Statistics

To better understand the variations in axle configurations seen in practice, the author analyzed ready mix truck sales data from seven popular truck resale websites, focusing on the ten states for this Thesis. In addition, this data was compared with sales data collected during the UT-CTR SHV analysis project (Walton et. al, 2017). The following table summarizes the sales data analyzed, with the Texas component being from the previously conducted study. Due to a lack of data from Michigan, that state has been excluded from the distributional analysis.

Table 3-5. Ready mix truck sales data summary

State	# of Trucks	# of SHVs	% of SHVs
California	201	147	72
Florida	276	42	14
Georgia	210	21	9
Illinois	42	24	57
North Carolina	177	114	63
New York	102	33	32
Ohio	150	72	46
Pennsylvania	96	84	88
Texas	1452	486	25
Michigan	6	6	100

Of the 2,992 ready mix truck sales records analyzed, 952 of them were varying types of SHVs, leading to an overall proportion of SHVs of 32%, with certain states having a higher proportion of SHVs in the sales data than other states. Also, it should be noted that this method of data collection does allow the possibility of repeat counts, since a truck could be registered for sale on multiple online sales portals.

To test the robustness of this SHV proportion statistic, the bootstrap method of statistical sampling was used. In short, the bootstrap method provides a stronger indication of central tendency by taking multiple samples from a sample of data, calculating a statistic, and then determining the overall averages of the statistic over all of the different sample runs. In the example of an arithmetic mean being calculated for a sample of data, the mean for the one sample may be skewed one way or another. However, the bootstrap method is used to produce multiple samples, sometimes hundreds of thousands of samples from that sample, computing the average of each of the samples, and then taking an average of all of the sample means. This procedure has been statistically proven to provide a better estimate of the true statistic.

Using the bootstrap method on the sales data and calculating the statistic of SHV proportion, after taking 10,000 samples of sample size 10,000 each, the average of SHV proportions was calculated to be 39.8%. In the overall bootstrapped data, the distribution of configurations was as shown in Table 3-6 and Figure 3-20.

Table 3-6. Proportion of SHV configurations in sales data

Configuration	SHV	Proportion (%)
1S-1	No	1.6
1S-2	No	58.6
1S-1L-2	SU4	7.3
1S-2-1B	SU4	22.9
1S-2-1L	SU4	3.6
1S-2L-2	SU5	0.3
1S-1L-2-1B	SU5	4.2
1S-1L-2-1L	SU5	0.3
1S-2L-2-1B	SU6	0.5
1S-1L-2-1L-1B	SU6	0.5
1S-2L-2-1L-1B	SU7	0.1

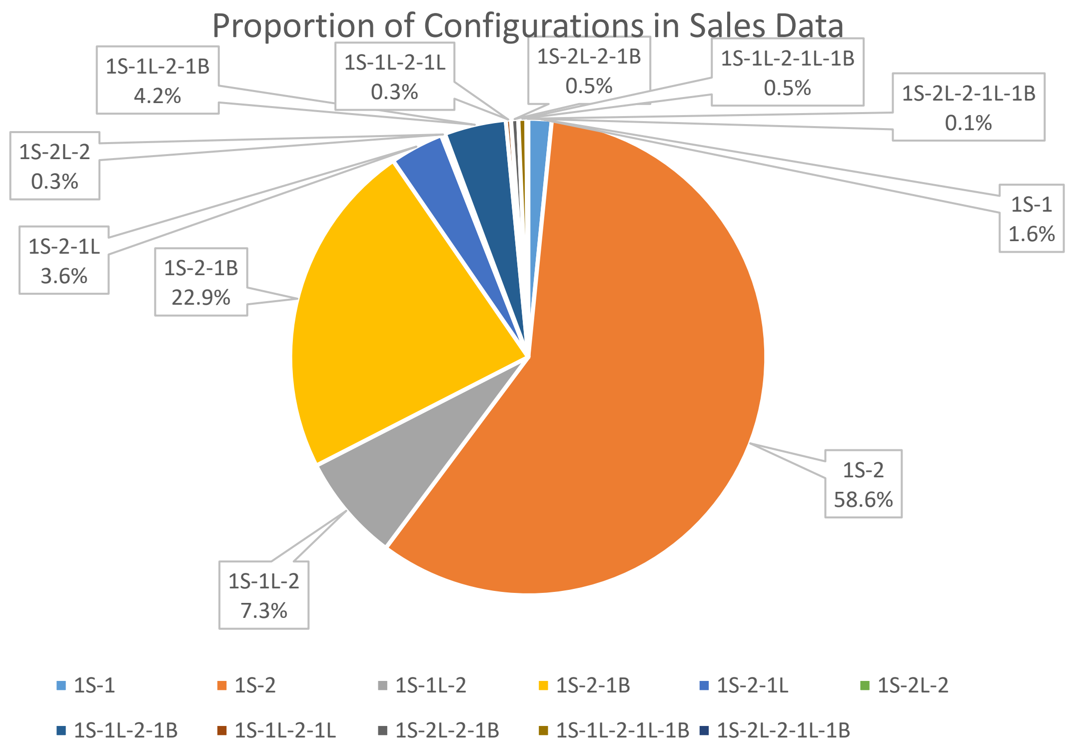


Figure 3-20. Proportion of SHV configurations in sales data

As the table and figure show, the largest proportion of ready mix trucks in the sales data were of the 3-axle configuration 1S-2 (59% of all trucks and over 97% of non-SHVs). The largest SHV configuration was the 4-axle booster configuration 1S-2-1B (23% of all trucks and 58% of SHVs), followed by the 4-axle pusher configuration 1S-1L-2 (7% of all trucks and 18% of SHVs).

The next chapter presents a discussion of analyses on lift axle regulations in states across the United States and analyzes an NCHRP survey that discusses, among other things, lift axle regulations in the US.

Chapter 4: Regulation Analysis

In this chapter, a discussion of the federal laws governing lift axle usage will be presented followed by a comparison of Administrative or Transportation codes from Texas and its peer states regarding SHVs and lift axles.

4.1 Federal and Texas Lift Axle Regulations

The Federal Bridge Formula (FBF) was enacted by Congress in 1974 to protect bridges from excessive loads by restricting the weight of a vehicle based on its axle configuration (number of axles and axle spacing) and ensuring a minimum distance between the outer most axles. The distance between the outer most axles, or the 'outer bridge length' is checked in addition to the various inner bridge length requirements to ensure every axle group complies with the bridge formula. All commercial vehicles, including SHVs, are subject to the formula when driving on a federal interstate highway. The formula is:

$$W = 500\,[(\frac{LN}{N-1}) + 12N + 36]$$

where:

"W" is maximum allowed overall gross weight on the axle group;

"L" is distance in feet between the axles of the group that are the farthest apart; and

"N" is number of axles in the group

This formula applies only to trucks traveling on federal highways (interstate commerce) or on state highways where the state has fully adopted the Federal Bridge Formula for its state and local roads and does not distinguish between type of truck. In addition to the FBF, federal law mandates that single axles be limited to carrying a maximum weight of 20,000 pounds, and axles closer than 96 inches apart (considered tandem axles) are limited to 34,000 pounds. In addition, two consecutive tandem axle groups spaced 34’ apart are limited to 68,000 lbs. GVW, the total weight of the vehicle, is limited to 80,000 pounds (23 U.S.C. § 127). Special permits for non-divisible loads or for states that have adopted higher weight limits for sealed ocean containers can allow for the carrying of more weight. However, this is not applicable for SHVs.

In Texas commercial vehicle operators must also adhere to the manufacturer’s maximum tire load rating during operations. Many commercial tires have two applicable maximum weight ratings, a rating when used as a single tire or when used as one tire in a dual tire assembly. When used in a dual tire assembly, allowable tire loads are less than the maximum load when operated as a single tire. The reason for this difference is to provide a factor of safety in the event one of the dual tires has a blowout. In that case, the remaining inflated tire will be carrying approximately one half of the total axle load.

In addition to the FBF, individual state laws also apply which can vary significantly from state to state for different types of trucks or trucks transporting specific types of cargo. For example, some states adopt the FBF for use on their own state highways, some adopt the FBF with modifications, while some have unique formulae for use. The following table shows how Texas and its peer states adopt the FBF ("Federal Bridge Laws / Vehicle Weight Laws", n.d.; USDOT, 2015).

Table 4-1. State Adoption of Federal Bridge Formula

State	Federal Bridge Formula?	Details	Source
California	Own Formula	There's no actual formula declared in California's statutes, but tables provided don't match Federal Bridge Formula. Also, a straight truck doesn't gain any additional weight allowance by adding any axles to the truck beyond the 4th axle.	Cal. Vehicle Code §§35001, 35550, 35780 et seq.
Florida	FBF with modifications	Non-Interstate travel is governed by the state outer bridge formula. State law allows up to 40,000 lbs. on a tandem axle. State law includes a 10 percent weight allowance for axle weight limits. Special exemption for dump trucks that allows a 4-axle dump truck to carry 70,000, which is the maximum GVW under the exemption. Ready mix trucks are exempted from meeting state axle spacing requirements.	Fla. Stat. Ann. §316- 500 through §316- 565 et seq.
Georgia	FBF with modifications	Adopted the FBF as its State bridge formula, but several provisions in state law allow exceeding of federal limits. Allows 20,340 lbs. on a single axle. Allows 40,680 lbs. on a tandem axle on non-Interstate highways. Allows 61,020 lbs. for a tridem axle on non-Interstate highways. Essentially, the FBF only applies to federal roads, and when the truck weighs between 73,280 and 80,000 lbs. Grandfathered laws allow for four-axle trucks to carry 70,000 lbs, regardless of axle spacing.	Ga. Code Ann. §§32- 6-20 et seq.
Illinois	FBF with modifications	Illinois uses a State Bridge Formula, which is adopted from the FBF, with some exceptions. Straight trucks are limited to 4 axles on the truck (any additional axles don't increase the allowable weight). Combination vehicles (trailers / pups / transfers) are allowed up to 6 axles. Illinois State statute allows for several axle and GVW exemptions for various types of vehicles. Vehicles registered as Special Haul Vehicles (SHV) have various axle and bridge formula exemptions except when using the National System of Interstate and Defense Highways.	Ill. Rev. Stat. ch. 625, §§5/15-101 et seq.
Michigan	FBF with modifications	Michigan has adopted the FBF state-wide, but also allows older grandfathered state law limits for trucks exceeding 80,000 lbs gross weight. Michigan has a grandfather provision under Federal law (23 CFR Part 658, Appendix C) to allow vehicles to operate up to 164,000 lbs. Michigan State statute allows for several axle and GVW exemptions for various types of vehicles and commodities.	Mich. Comp. Laws Ann. §257.722 et seq.

Table 4-1. (Continued)

State	Federal Bridge Formula?	Details	Source
New York	FBF with modifications	New York's state weight laws combine the FBF with a separate state formula: If the vehicle weighs less than 71,000 lbs, the formula W = 34,000 + (L * 1000) can be used if it allows greater GVW than the FBF. New York has a grandfather provision under Federal law (23 CFR Part 658, Appendix C) to allow vehicles to operate up to 143,000 lbs. New York allows 22,400 lbs. on a single axle in regular operation. New York allows 36,000 lbs. on a tandem axle in regular operation. New York State statute allows for several axle and GVW exemptions for various types of vehicles and commodities.	N.Y. Vehicle and Traffic Laws §385 and §386 et seq.
North Carolina	FBF with modifications	North Carolina's bridge table is based on the FBF, although the formula itself is not stated in the statutes. North Carolina differs from the federal weight law in that 38,000 lbs is allowed on tandem axles. North Carolina allows 38,000 lbs. on a tandem axle in regular operations. A 10 percent tolerance to State limits is permitted; however, the tolerance does not apply to single axle, tandem axle, or GVW limits. North Carolina allows a variety of commodity-specific weight exemptions.	N.C. Gen. Stat. §§20-115 et seq.
Ohio	FBF with modifications	Ohio has adopted the FBF state-wide, with some modifications. Ohio State statute allows for 7.5 percent tolerances above State axle weight and / or GVW limits for various commodities. Ohio State statute allows for several axle and GVW exemptions for various types of vehicles. For travel on non-Interstate highways, State law contains limits for single, tandem, and tridem axles in combination with base weights, with weight increases being based on spacing.	Ohio Rev. Code Ann. §§5577.01 et seq.
Pennsylvania	FBF with modifications	The gross weight of vehicles in regular operations (operating without a special permit) is governed by the State gross weight limits, the State axle weight limits, and the State bridge formula, which is adopted from the FBF. Regular operations limit vehicles to 22,400 lbs. for a single axle and up to 38,000 lbs. for a tandem axle. Pennsylvania State statute allows for several axle and GVW exemptions for various types of vehicles and commodities.	Pa. Cons. Stat. Ann. tit. 75, §§4901 et seq.

Table 4-1. (Continued)

State	Federal Bridge Formula?	Details	Source
Texas	FBF with modifications	Texas has adopted the FBF state-wide, with some modifications. Texas has several commodity-specific weight exemptions that apply to axle weights and GVW. Texas State statute exempts various types of vehicles from State weight limits. Ready mix trucks are allowed 23,000 lbs. on a single axle and 46,000 lbs. on a tandem axle on non-Interstate public highways. Vehicles may exceed these axle weights by 10 percent if the GVW is below 69,000 lbs. and the vehicle obtained a permit.	Tex. Transportation Code Ann. §621.001 through §623.343 et seq.

Texas is one of the states that adopts the FBF limits for all state-maintained roads (Luskin, Harrison, Walton, Zhang & Jamieson, 2000), with some alterations due to grandfathered old weight limits, such as a pre-existing law that allows higher loads for 4 axle trucks with specified outer bridge lengths. Furthermore, weight restrictions are placed on certain portions of the roadway and bridge network, based on load zone studies which determine the maximum allowable load due to inadequate structural strength, or in the case of bridges, structural deficiencies. Load zoned roads or bridges are clearly signed indicating the load limits. By the authority of the executive director of the Texas Department of Transportation, roads may be set for different maximum weight allowances if "heavier maximum weight would rapidly deteriorate or destroy the road or a bridge or culvert along the road" (Texas Transportation Code § 621.102). As an example, in Texas, the majority of Farm-to-Market (FM) road mileage was designed and constructed during the 1940s and 1950s for a maximum allowable GVW of up to 58,420 lbs for a 3-axle truck. The 58,420 lbs GVW load limit was originally set in 1950 based on calculations using the 1946 AASHO bridge formula. While some of these FM roads have been upgraded, 40% of the 41,000 centerline miles of FM roads in Texas still have a load limit restriction of

58,420 lbs. (Luskin, Harrison, Walton, Zhang & Jamieson, 2000). The 58,420 lb GVW load limit was applied to a significant portion of FM roads in Texas when the Federal Government announced that the national GVW load limit would be increased to 73,280 lbs in conjunction with the 1956 Interstate Highway Bill. To protect the significant investment that Texas had made in paving thousands of miles of FM roads, they were load zoned through a single Commission Minute Order.

Texas Transportation Code, Sec. 621.101 puts forth the legal weight limits for Texas, which are the same as federal regulations. However, weight or dimension exemptions exist for trucks of particular industries. For example, Texas Transportation Code, Sec. 622.012 states that a ready mix concrete truck may be operated on a public highway of the state if the tandem axle weight is not heavier than 46,000 pounds and the single axle weight is not heavier than 23,000 pounds. This results in a higher GVW (69,000) than would be allowed by federal law. However, trucks operating at these higher weights are not permitted on the interstate highway system if the load is divisible.

In Texas, the maximum legal weight allowed on a group of two or more axles depends on the number and spacing of the axles in the axle group and is determined by using the FBF and rounding the result to the nearest 500 lbs. These laws govern the SHV configurations and axle weight limits that operate in Texas.

4.2 Lift Axle Laws outside of Texas

State policies regarding SHVs and lift axles vary from state to state. Two basic types of laws regulate lift axles: laws regarding equipment used to lift (what equipment, its placement, and other such considerations) and laws regarding configurations / weight carried.

Laws regulating lift axles were examined from different states and analyzing a comprehensive study on lift axles conducted by the Transportation Research Board's National Cooperative Highway Research Program (NCHRP).

This Thesis focuses on Texas and nine peer states identified by the 2030 Committee, a committee formed in 2008 at the request of the Texas governor tasked with providing an independent, authoritative assessment of the state's transportation infrastructure and mobility needs from 2009 to 2030. (Texas 2030 Committee, 2011). The peer states identified by the 2030 Committee includes: California, Florida, Georgia, Illinois, Michigan, New York, North Carolina, Ohio, and Pennsylvania. These states were chosen because of their similarities to Texas in terms of population, development, economic activity, and other key demographics.

Regarding lift axles in the US, there is a lack of uniformity regarding state truck weight laws, state statutes that allow higher load limits for trucks of a certain type or that carry a certain commodity; either year-round or seasonally, truck configuration and lift axle terminology. In terms of trucking jargon, it is recommended that standardized terminology be developed to reduce confusion. The method used to denote SHV configurations in this Thesis has been effective in describing SHVs during research and interviews with representatives of the trucking industry, and are proposed as a potential standard. The author suggests that slang terms such as cheater, dead, or dummy axles are not used, since these terms have an inherent negative connotation attached.

4.3 TEXAS AND PEER STATE LAW REVIEW

State laws were examined for each of the ten states by reading state laws (administrative codes), looking for mentions of lift axles, with a focus on laws regarding the ready mix industry. Relevant information was generally found in each state's Vehicle

Code, which is part of the larger set of statutes of the state. All were available online, with citations provided in the table. Beyond the Vehicle Code, documents from the state's department of transportation, especially the Vehicle Permitting offices, and the Highway Patrol's Commercial Vehicle Enforcement offices were researched, to find policies more specific than the Vehicle Code. The following tables compare Texas laws to those of the selected peer states. Note that this table does not express laws specifically pertaining to the ready mix industry.

Table 4-2. US Laws Regulating SHVs (from Texas and Peer States) (as of July 2019)

State	What the Laws Say	Source
California	For extralegal weight, Lift axles are acceptable for extralegal weight if they meet these two simple tests: 1) The lift axle loading group shall have common suspension and, 2) all axles in the loading group shall meet the +/- 10% equal weight distribution requirement. The lift axle controls shall be located outside the cab and inaccessible to the driver while driving.	Transportation Permits Policy Memorandum Policy 102-99
Florida	Lift axles must be in a load carrying position if required by permit. The load on a lift axle should be equipped with exterior lock requiring the driver to step out of the cab to release load on axle. According to CDL Handbook, inspection states: If retractable axle equipped, check condition of lift mechanism. If air powered, check for leaks.	Comdata Permit Limits for states Florida Commercial Driver License Handbook
Georgia	No lift axle may be used in computing the maximum total gross weight authorized for any vehicle or load. When applying the Federal Bridge Formula, no lift axle shall be counted as an individual or additional axle when determining the maximum overall gross weight.	Georgia Code 32-6-26
Illinois	Inspection procedures for lift axles were described, but have been repealed in Sept 2016. While a driver may have a rational and articulable reason for raising an adjustable axle, the letter of the law governing an overweight permit says they cannot lift it at all. For Lift or Pusher axles: Maximum weight variance between axles in a group is 2,000 pounds. Loads exceeding these dimensions or weight are considered as superloads. Lift axles are not considered for routine issuance.	Illinois Administrative Code 92-1-e-448-A Illinois Routine Permit Limits Illinois Trucking Enforcement Association

Table 4-2. (Continued)

State	What the Laws Say	Source
Michigan	Michigan's OW laws are all related to individual axle loading, not GVW. Laws "imply" that lift axles are mainly to be used to negotiate turns / intersections. Axle loadings for OW determinations shall only be done with lift axles lowered. For routine permits, lift axles must be full weight bearing axles. For special permits, vehicles must have air or lift axles on the ground at all times for which the permit is issued.	Michigan Compiled Laws 257.724a MDOT Special Provisions, Conditions and Restrictions Governing Special Transportation in Building Moving Permits on the State Trunk Lines
New York	Lift axles must be steerable and trackable. Any air pressure controls must be located outside of the cab, beyond the reach of occupants of the cab while vehicle is in motion. All axles other than liftable axles must have two tires on each side. For routine issue permits, lift axles must be a full weight bearing axle. Must be down and locked at all times. From Jan 1, 2020, vehicles with model years 2005 and older operating under Divisible Load overweight permits shall have steerable / trackable lift axles, have air pressure controls outside of the cab, and the weight on any grouping of two or more axles has to be distributed such that no axle in the grouping carries less than 80% of any other axle in the grouping.	New York Codes, Rules, and Regulations. 154-2.4 New York State DOT Central Permit Office: DLN 14-01 and DLN 13-02
North Carolina	No information specific to liftable axle SHVs but delineates permits for irregular weight / size vehicles. In permits, lift axles are considered as a legal axle, and must be a full weight bearing axle.	North Carolina Statutes. 20-119

Table 4-2. (Continued)

State	What the Laws Say	Source
Ohio	For determination of legal axle, axle group, and gross weights: lift axles must be load-bearing axles and weights cannot exceed the tire or axle load limit. When operating with a Special Hauling Permit: all load bearing axles and axle groups must be designed to equalize load over all axles of the group 16’0” or less. Variable load suspension axles or groups of axles not having the same suspension type are not recognized in overweight permit allowances. However, an airlift axle may be utilized and recognized if it is part of an air-ride suspension system and operates off of an equalizing valve common to all axles in the group, 16’ 0” or less. The lift axle controlling mechanism must be located outside the cab of the truck and mounted out of the driver’s reach during normal vehicle operation. In cases of carrying Superload: The Department recognizes that the use of lift axles is necessary for overweight Superload weight distribution and these axles must be lifted during some turning maneuvers. When such axles are in use and listed as load bearing axles on an overweight superload SHP, they shall remain in the fully lowered position except during turning maneuvers where there would be excessive tire and pavement scuffing or control of the vehicle would be hindered. Such axles shall be part of an air ride suspension group designed to equalize the load over all axles in the group, including the retractable axles.	Ohio Department of TransportationSpecial Hauling Permit Section - Lift Axle Policy
Pennsylvania	Except when necessary for turning a truck that is operating under normal load conditions, the lift axle shall be in full contact with the highway under full pressure. Lift axles must be utilized any time one of the other axles would be overweight without the use of the lift axle, and whenever the vehicle is operating under normal load conditions (more than 2/3 loaded by weight)	2010 Pennsylvania Code 49:4943 PennDOT Trucker's Handbook
Texas	No information specific to liftable axle SHVs. A lift axle is considered a legal weight bearing axle as long as it is on the ground and carrying its fair share of the load.	Comdata Permit Limits for states

Table 4-3. US Laws Regulating SHVs (from Other States) (as of July 2019)

State	What the Laws Say	Source
Idaho	Any vehicle which is equipped with variable load suspension axles (lift axles) transporting overweight loads shall have all lift axles fully deployed.	Idaho Administrative Code 39-03-13
Kentucky	A lift axle that isn't always deployed shall not be used in computing the maximum total gross weight authorized for any vehicle or load.	Kentucky Statute Chapter 177
Louisiana	When “Variable Load Suspension” axles are equipped on a vehicle and are operational, they must provide for reasonable distribution of axle weight. In addition, the regulator that controls the pressure for these axles must be outside the cab. The only control that may be in the cab is that which is necessary to activate the mechanism. The suspension used by these axles may be either hydraulic, air or a combination thereof.	Louisiana Regulations for Trucks, Vehicles and Loads (DOT)
Maine	For all vehicles manufactured, modified or retrofitted with liftable or variable load suspension axles after October 30, 1991, liftable or variable load suspension axles are permitted only under the following conditions: only one liftable or variable load axle may be present on the truck tractor and only one liftable or variable load axle may be present on the semitrailer; liftable or variable load axles must be located on the vehicle so that they are legally part of the tandem axle group or tri-axle group as appropriate; and the axle weight rating of liftable or variable load axles must conform to the expected loading of the suspension and must be 20,000 pounds or more. When operating at a gross vehicle weight exceeding 88,000 pounds, all liftable axles of the vehicle are in full contact with the ground at all times. Axles 2, 5 and 6 of a six-axle singly-unit vehicle may be liftable axles. Axles 2 and 6 must be self-steering axles of a type that has been approved by the Department of Transportation.	Maine Revised Statutes 29-21-1-2354/2364/2365
Maryland	Maryland currently only has lift axle regulations for four-axle-or-more trucks. Lift axle control shall allow only fully on or fully off. These controls may be in cab of vehicle, but air pressure adjustment control cannot be. There are specific rules about when the lift axles can be engaged and disengaged (such as when turning sharp curves). Also, weight limits and minimum lift axle loadings are specified, in relation to GVW.	Code of Maryland 11.15.27.05 and 07
Minnesota	A vehicle or combination of vehicles equipped with one or more variable load axles shall have the pressure control preset so that the weight carried on the variable load axle may not be varied by the operator during transport of any load. The actuating control for the axle shall function only as an on-and-off switch. This doesn't apply to old farm trucks and general rear-loading refuse-compactor vehicles.	Minnesota Statutes 169.828

Table 4-3. (Continued)

State	What the Laws Say	Source
Montana	If a motor vehicle is equipped with a retractable axle that is not fully extended and carrying its proportionate share of the load while the motor vehicle is operated upon the highways of this state, the weight penalties in subsection (1) apply to all weight over the legal maximum allowed by the fixed axles regardless of whether the axle is extended at the time of weighing. In addition to the penalties in subsection (1), the owner or operator shall be fined $100 for failure to have the retractable axle fully extended while the gross weight of the vehicle exceeds the legal maximum allowed by the fixed axles.	Montana Code Annotated 61-10-145
New Hampshire	SU4 vehicles shall drive on 2 rear axles, and the tridem may contain no more than one retractable axle.	New Hampshire Revised Statutes Title XXI: Chapter 266
North Dakota	On all motor vehicles manufactured after July 31, 2005, the lock or pressure regulator valve for a lift axle shall be located outside the cab and inaccessible from the driver’s compartment only if there is more than one lift axle. The control to lift and lower a retractable or variable load suspension axle may be accessible in the driver’s compartment.	North Dakota Highway Patrol Weight / Size Guide
Oregon	The controls for the lift axle may be mounted inside the cab of the power unit provided that it limits the axle movement to the complete up or complete down position; The control for a variable load, or lift axle, which allows adjustment to increase or decrease loading on the vehicle must not be accessible from the cab; The lift or variable load axle must be deployed, and distribute the weight of the load, when failure to do so results in any tire, axle, tandem axle or group of axles exceeding the weight limits allowed; All single axles of triple trailer combinations must have four tires except for the steering axle of the power unit and lift axles which may have two tires; Raising a lift-axle is not considered a change in configuration (for tax)	Oregon Administrative Rules 734-074-0010
South Dakota	Unless specifically authorized by permit, a variable load axle may not be raised if, when it is raised, it causes any other axle to be overloaded. The control for adjusting pressure shall be mounted outside of the driver compartment and shall be preset so the weight carried on the variable load axle may not be varied by anyone in the vehicle. The control for raising and lowering the variable load axle may be accessible to the driver, but it may not also function as the pressure control device. Permits can be bought that allow lifting of axle when making turns. Lift axles and belly axles are not considered load-carrying axles and will not count when determining the vehicle’s weight limits.	South Dakota Code SDCL 32-22-57.1 and South Dakota Motor Carrier Handbook Chapter 5

Table 4-3. (Continued)

State	What the Laws Say	Source
Utah	Retractable or variable load suspension axles installed after January 1990 shall be self-steering on power units or when augmenting a tridem group on trailers; no axle in a group with a retractable or VLS axle shall exceed legal or bridge formula weight requirements, or the manufacturer's tire rating; Controls for raising or lowering retractable or VLS axles may be located in the cab of the power unit. The pressure regulator valve shall be positioned outside of the cab and be inaccessible from the driver's compartment.	Utah Admin Code R909-2
Washington	The axle must be self-steering. The simple "up / down" control may be in the driver's compartment; however, any variable control used to adjust axle loadings, by regulating air pressure or other means, must not be within reach of the driver's compartment. The self-steering requirement does not apply when: (a) The retractable axle, equipped with four tires, is used for the purpose of weight distribution on a truck or truck-tractor and gives the appearance of, but does not function as, a tandem axle drive configuration. The distance between the drive axle and the retractable axle must not exceed sixty inches. b) A retractable axle is used adjacent to a fixed axle on a trailing unit and distance between the two axles does not exceed sixty inches.	Washington Administrative Code WAC 468-38-280
Wisconsin	The control valve that regulates the amount of pressure shall be mounted outside of the driver's compartment; The control valve that regulates the movement of the axle or axles so as to raise or lower the axle or axles may be in the driver's compartment. Lift axle must carry a minimum of 8% of gross load when used.	Wisconsin Administrative Code. Trans 305.49
Wyoming	If any axle group containing a variable load suspension axle exceeds legal or allowable weight without using the variable load suspension axle, the variable load suspension axle shall be used to the extent that it assumes sufficient weight to keep the axle group with which it is used within legal weight for a divisible load or permissible weight for a non-divisible load. Lift axle must bear at least 8% weight of axle group. Vehicles equipped with a functional variable load suspension axle shall be required to put the axle into use if the vehicle is overweight and the use of the axle will reduce the amount of overweight on an axle group, inner bridge, or gross. In certain cases, the use of this type axle may reduce the allowable weights a vehicle may carry. If the allowable weight is reduced due to decreased bridge between axle groups, the use of the axle is not required.	WYDOT Rules, Motor Carrier Chapter 5

Some items to note in the above table include the following:

- Four states have no specific laws regarding lift axles in their statutes (Illinois, North Carolina, Ohio, Texas).
- One state effectively 'bans' the use of lift axles (Georgia) by disregarding them when computing maximum loads permitted. Meaning, in Georgia, an SHV with four lift axles and three fixed axles will have an allowable GVW limited to what can be carried by the three fixed axles.
- Four states have regulations controlling where the control mechanism must be placed (California, Florida, New York, Ohio).
- Two states recognize the potential damage that can occur to tires and pavements during turning movements and allow trucks to lift axles immediately before turning maneuvers (Michigan, Pennsylvania).
- The author surmises that two significant motivations or influences behind why lift axles vary from state to state are the needs of the industry. For example, in terms of introducing new allowed configurations, industry representatives identify a configuration that they believe would improve their operations. This configuration is proposed to members of the legislature. Research is conducted to assess the benefits and costs of such a configuration, and it is brought to a vote. If approved, the law is implemented. The other direction for the development of statutes may be from enforcement. In the example of configurations, if law enforcement notices a problem with any particular configuration, such as an increased rate of crashes, they can bring that up to legislature in the form of reports.

4.4 NCHRP 575

NCHRP 575 was published in 2007 and documented an extensive study to determine the types of SHVs operating in the US for the development of SHV bridge load diagrams (Sivakumar, Moses, Fu & Ghosn, 2007). Beyond providing basic information such as how lift axles function, the report contains a survey summarizing states SHV regulations. The report states that "criteria for lift-axle design and operation are contained in AASHTO's Guide for Maximum Dimensions and Weights of Motor Vehicles and for the Operation of Non-Divisible Load Oversize and Overweight Vehicles," and mentions that several states have adopted the AASHTO guidelines as regulations. These AASHTO guidelines specify the following criteria for vehicles serving in regular operations (Sivakumar, Moses, Fu & Ghosn, 2007):

"In computation of gross vehicle or axle weight limits for highway legal vehicles not requiring oversize / overweight permits, no allowance will be made for any retractable or variable load suspension (VLS) meeting the following criteria:

- All controls must be located outside of and be inaccessible from the driver's compartment.
- The gross axle rating of the VLS devices must conform to the expected loading of the suspension and shall in no case be less than 9000 pounds.
- Axles of all retractable or VLS devices manufactured or mounted on a vehicle after January 1, 1990 shall be engineered to be self-steering in a manner that will guide or direct the VLS mounted wheels through a turning movement without the tire scrubbing or pavement scuffing.

- Tires in use on all such axles shall conform in load capacity with relevant State regulations or with Federal Motor Vehicle Safety (FMVS)." (Sivakumar, Moses, Fu & Ghosn, 2007).

The NCHRP report provides the results of a survey on lift axle regulations sent to the states, as are shown in the table below. A total of 44 states are included in the responses.

Table 4-4. NCHRP 575 Survey Questions about Lift Axle Regulations

Survey Questions on Lift Axles	DOT Responses		
	Yes	No	Not Sure
Question 4.1 Does your agency permit the use of liftable axles on heavy trucks?	41	3	
Question 4.2 Do any of the state legal loads used by your agency represent trucks with liftable axles?	14	28	
Question 4.3 Does your agency or state monitor the weight carried by the liftable axles to ensure compliance with state regulations?	21	5	5
Question 4.4 When performing load ratings for trucks with liftable axles, are ratings checked with the axles in the raised position under full load?	3	15	

Of the peer states used in the analysis outlined in Chapter 3, eight out of ten respondents also participated in the NCHRP survey (Michigan and Pennsylvania did not). All answered 'yes' to Question 4.1, three answered 'yes' to Question 4.2 (New York, North Carolina, and Ohio), Texas answered 'no' to Question 4.3 while Ohio was 'unsure', and all states except for New York and Illinois said they 'do not include lift axles in load ratings' for Question 4.4.

4.5 Commercial Vehicle Law Enforcement Contact / Survey

Beyond differences in regulations, the variation in the practical application of these regulations is also important. Law enforcement personnel were contacted to gain more insight into the practical application of these laws.

As mentioned, different agencies with knowledge of state regulations regarding lift axles were contacted in Texas and in peer states. Communications were conducted through e-mail or phone, and respondents either filled out the online anonymous survey or answered questions over the phone. Appendix A shows the survey, while Appendix B shows the contacts made.

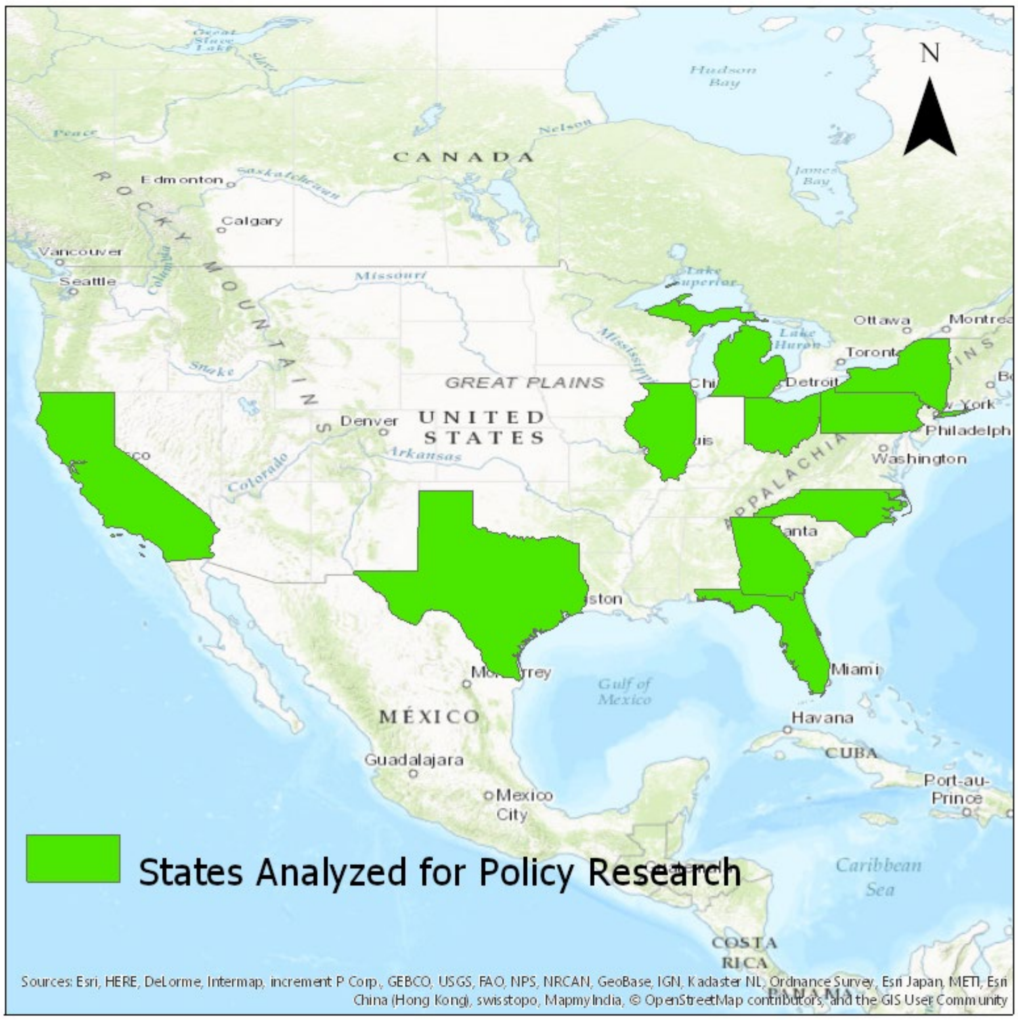


Figure 4-1. US map showing the states analyzed for policy research

Of these ten states, seven representatives spoke over the phone or identified themselves in the survey, while three representatives (Florida, Michigan, and New York) filled out the survey anonymously. The major results of the survey are provided in this section.

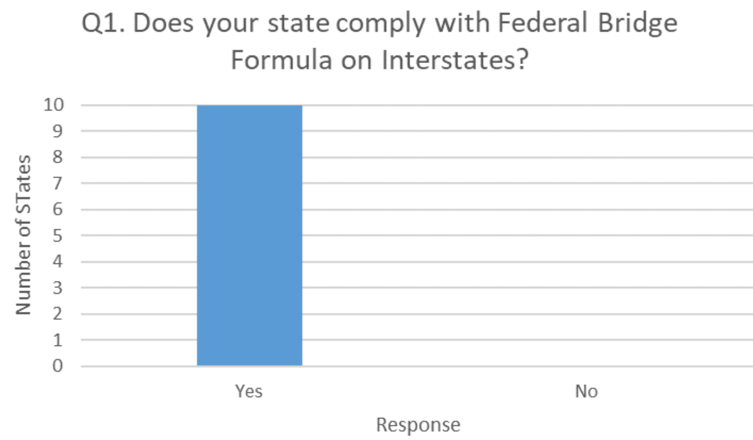


Figure 4-2. Question 1 on policy survey (state compliance with the FBF)

Although all states responded by saying ‘yes’ to whether or not their state complies with FBF on interstates, a few answers had exceptions. California laws comply with the FBF up to the fourth axle (no added weight is allowed after fourth axle, without an increase in length to meet FBF requirements). Florida follows the FBF, but has an exemption for dump trucks, ready mix trucks, refuse trucks, and oil trucks that exempt these trucks from meeting state axle spacing requirements. Any of these vehicles are limited to a single axle limit of 20,000 lbs. and 550 lbs. per inch tire width plus scale tolerances, up to a total gross vehicle weight of 70,000 lbs. Georgia allows trucks to carry weights in accordance with old state laws, which allow four-axle trucks to carry 70,000 pounds. Illinois follows the FBF up to the sixth axle.

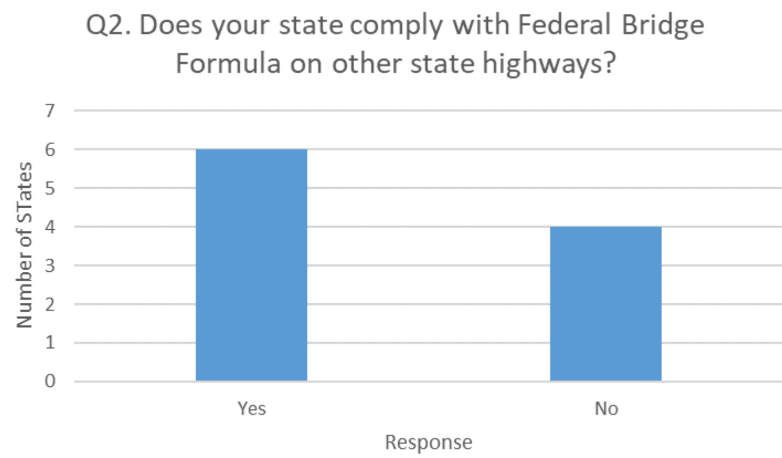


Figure 4-3. Question 2 on policy survey (state compliance with the FBF on non-interstates)

Similar to the exceptions in the previous question, some states adopt the FBF, but with modifications. For example, North Carolina follows the FBF, except its regulations allow 38,000 pounds on tandem axles (as opposed to 34,000). Michigan, however, has a unique set of regulations, which are not based on GVWs, but rather on individual axle weights. The maximum number of axles allowed in Michigan is eleven, while per-axle load regulations result in a maximum GVW of 164,000 pounds. Straight trucks are limited to 40’ in length, and there are regulations controlling individual axle loadings with regards to axle spacing (MDOT, 2007).

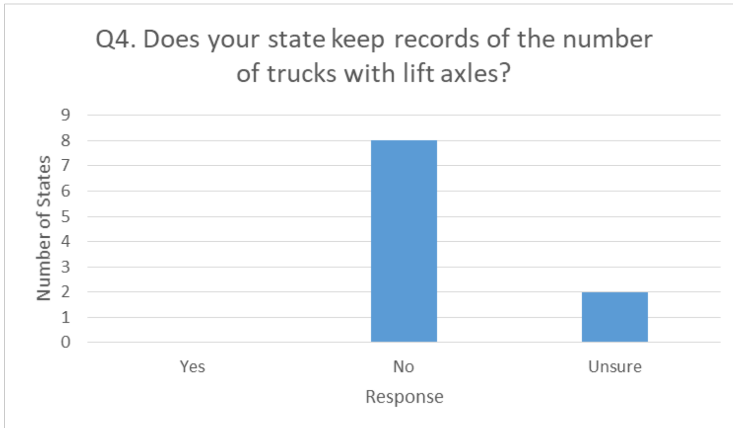


Figure 4-4. Question 4 on lift axle records

The fourth question of the survey asked if states, at any stage of a truck's operation, recorded data regarding the presence / usage of lift axles, i.e. during truck registration or during a weight enforcement stop. No state answered 'yes'. Texas included, and the TxDMV interview provided the author with more details. TxDMV employees explained that, because it was not legally mandated to take axle type into account during registration, this data was not collected.

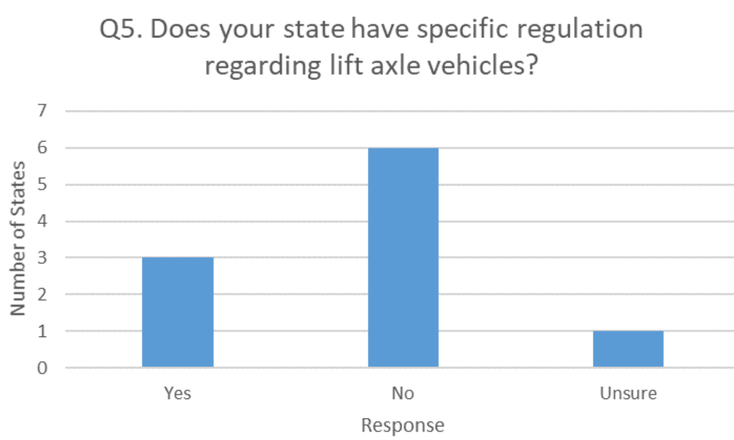


Figure 4-5. Question 5 on policy survey (lift axle regulations)

The fifth question of the survey asks about any specific lift axle regulation. Three states answered ‘yes’:

- Georgia – Lift axles are ignored when computing axle allowances (effectively banning use). Meaning, in Georgia, an SHV could be configured with many lift axles, but would be limited to carry a GVW calculated based on its fixed axles only.
- Michigan – Lift axles must stay on the ground when truck is loaded, unless turning maneuver requires them to be raised.
- Pennsylvania – Lift axles must stay on the ground when truck is at least two-thirds loaded, unless turning maneuver requires them to be raised.
- New York answered ‘unsure’, but a review of the legislation reveals laws regarding placement of the control mechanism.

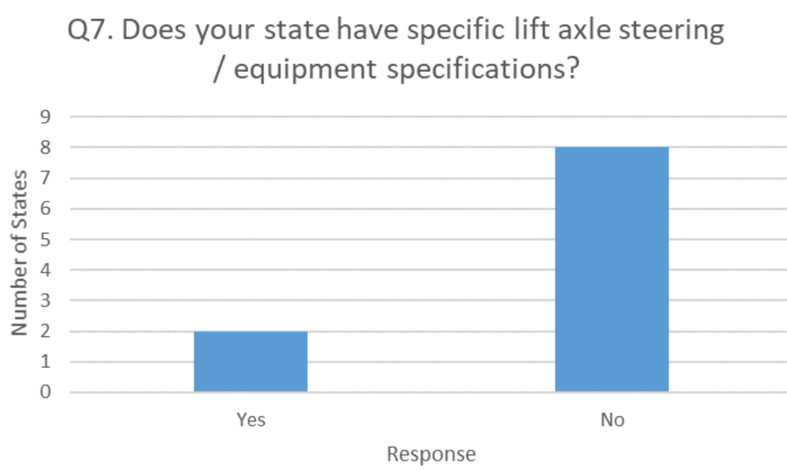


Figure 4-6. Question 7 on policy survey (lift axle equipment regulations)

Two states answered ‘yes’:

- New York: Lift axle must be steerable and trackable (similar to AASHTO guidelines mentioned in NCHRP Report 575).

- Ohio: Lift axle must be a load-bearing axle.

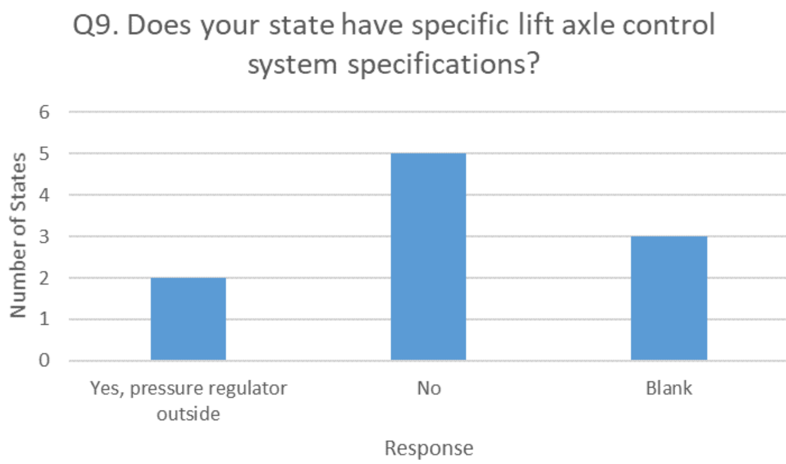


Figure 4-7. Question 9 on policy survey (lift axle control regulations)

Georgia and New York have laws requiring the pressure control mechanism to be placed outside of the driver's reach when the vehicle is in motion. Texas has no regulations for controls.

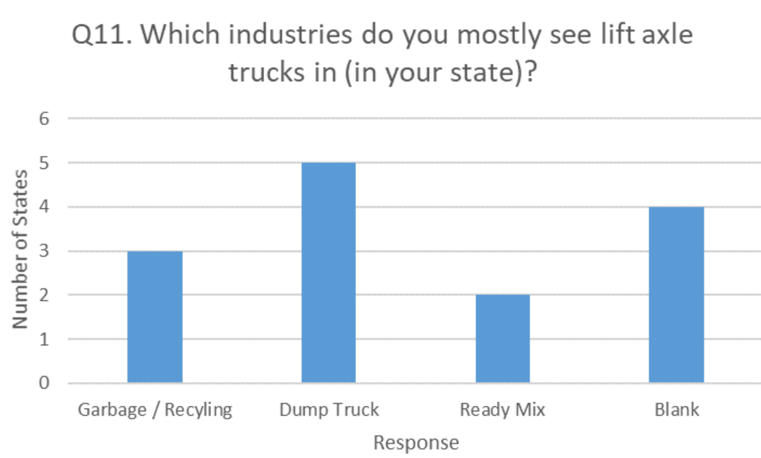


Figure 4-8. Question 11 on policy survey (common lift axle industries)

When asked which industries in their state use lift axles, all enforcement representatives selected an industry that matched with the count data in Texas.

Noteworthy insights gleaned from phone interviews include the following:

- The contact from the California Highway Patrol mentioned that, at a certain point, it isn't feasible for trucking companies to add more axles with lift axles, because "economies of scale" have been reached. He referred to this as the law of diminishing returns, where trucks' incremental gain in payload capacity decreases with each increase in axle numbers, especially without a corresponding gain in truck length. California is an example since allowable weight limits do not increase after the fourth axle is added unless the outer bridge length is increased. This leads to SHVs with fewer axles being popular, e.g., four-axle configurations such as 1S-1L-2, 1S-2-1L, etc.

This chapter described work this author has done on a related University project, a synthesis of a 2007 study which included a survey on lift axle regulations, the author's work in documenting lift axle laws in several US states, and the results of the author's contact (survey / interview) of law enforcement personnel.

The results of the law analysis previously in this chapter were echoed throughout the survey / interview results, i.e. contacted states do not record lift axle presence / usage as part of regular enforcement procedure. There is also great variability in the law regulating lift axles around the country, with most of the sample set (six) of states having no specific laws of any kind. Only one state (New York) mandates steerable lift axles, as recommended by AASHTO in NCHRP Report 575. Further research should be done to investigate the effect of non-steerable axles on pavement wear and safety. The next chapter describes the results of industry research efforts with regards to lift axles in the ready mix industry.

A ready mix industry trade association's surveys of its members are analyzed in the next chapter. Also, truckers, lift axle manufacturers, and other trucking company representatives were contacted to gather information about the ready mix industry's perspective on lift axles. Truckers were asked to respond to an anonymous survey or comment anonymously on a trucking forum. The next chapter summarizes these research efforts, including describing the methodologies and discussing the results.

Chapter 5: Interviews and Survey Analyses

Data for this Thesis were gathered by conducting surveys and interviews with separate groups of people representing the industry. Two main surveys were analyzed in this chapter: a set of annual surveys administered by an industry trade group, the National Ready Mix Concrete Association (NRMCA), as well as a survey administered to trucking company representatives by the author of this Thesis. Appendix C contains the survey sent to trucking companies based in Texas with questions regarding company operations and motivations for using SHVs.

Ready Mix companies in Texas and peer states were identified to receive a copy of the survey. The company names were selected by searching through the database of the National Ready Mixed Concrete Association's member directory, as well as the trade associations for the concrete industry within each state. Representatives from these associations were also contacted and asked to share the anonymous survey link with their members.

In addition, five international online forums were used to ask ready mix truckers all over the world to respond to the survey. The post made on the forums is in Appendix D.

Survey taker's names were kept confidential (unless waived) and. as such, the results of the survey / interviews do not include the names of the respondents or their company affiliations. The author determined that the option to remain anonymous would result in respondents being more comfortable with completing the survey.

Once these contacts were made, the results of the survey were analyzed; notable responses are presented in this Thesis. It should be noted that this interview / survey methodology for the industry analysis did gather results that are statistically significant.

Based on the total number of ready mix companies – 2,103 as of 2019 ("Ready-Mix Concrete Manufacturing in the US", 2019) - the author determined that a sample of 239 or more unique company responses was required for significant results for a 90% confidence interval with a 5% margin of error. The results shown are from the analysis of 249 responses. However, the methodology behind the survey, to be explained later in this Thesis, did account for the possibility of multiple surveys from the same company.

The survey was developed considering survey questions from the 0-6897 SHV study conducted by UT-CTR. The survey begins with questions about the company's truck fleet (how many ready mix trucks, how many SHVs). For respondents with zero SHVs, the survey asks questions to understand company motivations for not operating SHVs and plans, if any, to operate SHVs in the future. For companies that operate SHVs, SHV truck trends were determined to predict whether SHV numbers will be increasing or decreasing in the future. Company representatives were asked to discuss their company's motivation for operating lift axles. The survey also asks all respondents about SHV safety, as well as geographical information, to gain an understanding of possibly varying views regarding SHVs in different parts of the country. The following sections present the results of the NRMCA survey followed by the survey conducted for this study.

5.1 NRMCA Survey Analysis

The NRMCA distributes several different types of surveys to its members each year. One of these surveys is the Fleet Benchmarking and Costs Survey, which is distributed to concrete producers to obtain information about ready mix concrete truck fleet maintenance and utilization. The survey was developed, and responses analyzed by the NRMCA Operations, Environmental, and Safety Committee. The author combined the results from eleven past, annual survey reports and analyzed the data to learn about lift axle usage in the ready mix industry (NRMCA, 2006, 2007, 2008, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017).

The NRMCA survey asks numerous questions regarding topics such as Region, Mixer Fleet (which is the NRMCA's way of describing configurations), Fuel Consumption and Tire Information. However, as two of the objectives of this Thesis research are 1) to understand the numbers, types and configurations of SHVs in the ready mix industry and 2) to understand factors which may or may not motivate ready mix companies to operate SHVs, the segment of this survey of greatest interest is: Mixer Fleet (to understand composition of fleet and proportion of SHVs).

The survey divides the US into eight geographical regions, shown in Figure 5-1.

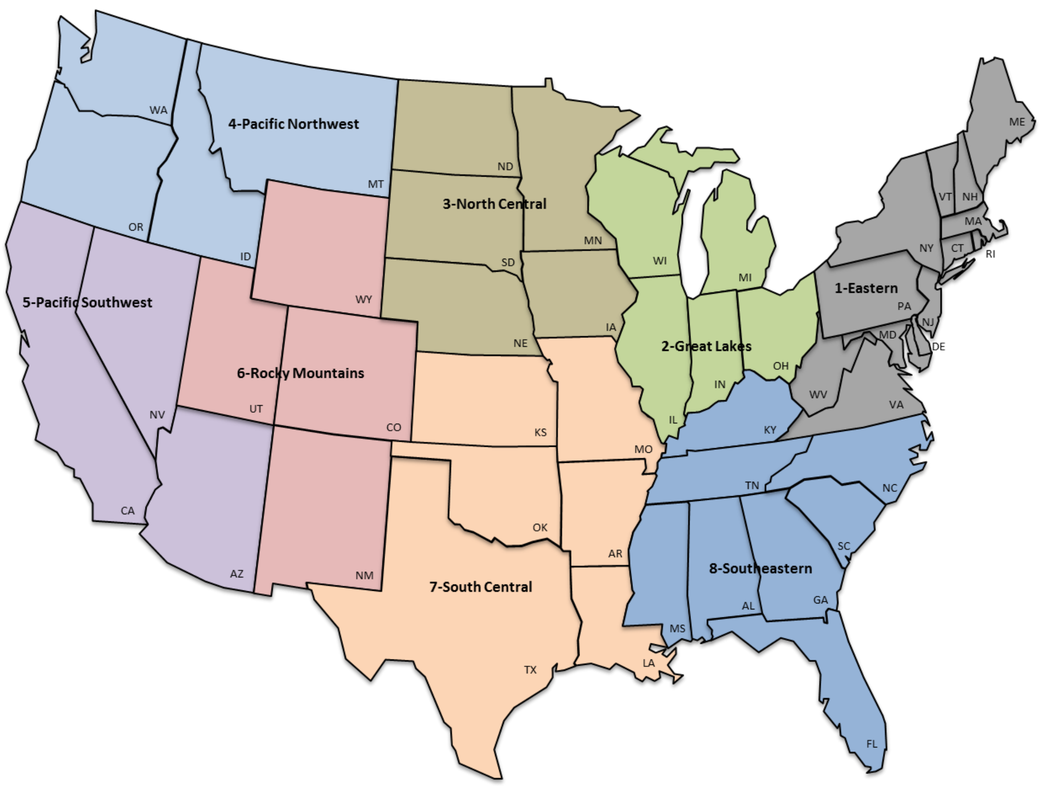


Figure 5-1. NRMCA Regions

As can be seen in the figure, the ten peer states are contained within five of the eight regions. The three regions which don't contain any of the ten peer states account for, on average, 13% of the total survey responses, as can be seen in Table 5-1. Interestingly, those three regions have the three lowest response percentages overall.

Table 5-1. NRMCA Survey Response Geographical Spread (2006-2017)

Year	South-eastern	Eastern	Great Lakes / Midwest	South Central	Pacific Southwest	Rocky Mountain	Pacific Northwest	North Central
2006	20%	20%	16%	12%	16%	7%	5%	4%
2007	16%	23%	14%	8%	20%	6%	8%	4%
2010	22%	23%	13%	16%	13%	6%	3%	5%
2011	20%	22%	13%	17%	15%	5%	3%	4%
2012	19%	24%	15%	16%	16%	5%	1%	3%
2013	24%	24%	18%	13%	12%	1%	1%	6%
2014	27%	21%	8%	12%	16%	3%	1%	8%
2015	27%	21%	8%	12%	16%	3%	1%	8%
2016	25%	19%	10%	16%	6%	1%	3%	7%
2017	23%	13%	9%	15%	20%	4%	10%	5%
Avg	**22%**	**21%**	**12%**	**14%**	**15%**	**4%**	**4%**	**5%**

In the Mixer Fleet section of the survey, participants are asked to denote the number of mixers in their fleet, as well as numbers of front-discharge and rear-discharge units. Survey-takers later are asked to expand on the compositions of their fleets by axle configurations. The configuration results from the most recent survey in 2017 are shown in Table 5-2.

Table 5-2. NRMCA 2017 Survey Response - Chassis Configuration

Description	Companies Reporting	Total Number	Average per company reporting	High	Low	Median
2-Axle	5 (6%)	5	3	4	1	3
3-Axle	31 (29%)	4,118	129	709	1	55
4-Axle / Booster	53 (65%)	5,276	101	546	2	64
4-Axle / Pusher	31 (38%)	770	30	131	2	17
5-Axle	40 (49%)	3,639	91	478	1	60
6-Axle	31 (38%)	2,261	73	372	6	61
7-Axle	6 (8%)	417	52	347	1	7

As the table shows, the distributions for all the truck configurations are skewed distributions: the median of truck numbers for a given configuration is significantly lower than the average number of trucks. This describes a right-skewed distribution, which means that there are more trucks on the higher weight end of the spectrum. This may be due to trucks with 6 or 7 axles gaining the ability to carry proportionally more payload with the increasing number of axles.

Also, the only category with strict mention of any types of lift axles are the "4-Axle / Booster" and "4-Axle / Pusher" categories. These are "1S-2-1B" and "1S-1L-2" SU4 truck configurations respectively. It is noted that the categories for ready mix trucks with from 5 to 7 axles do not specify that these trucks have lift axles. The author concludes that the reason lift axles weren't categorized for those axle configuration options is because there are many configuration variations to justify separate categories.

For the purposes of this Thesis analysis, it is assumed that all trucks, from 4-Axles and above, have at least one lift axle of some kind. The analysis on truck sales data from Chapter 3 supports this assumption, as less than 0.005% of sales listings were for a truck with more than three axles, with no lift axles. Under that assumption, Table 5-3 shows the proportion of lift axles throughout the survey years.

Table 5-3. NRMCA Survey - Proportion of Trucks with Lift Axles 2006 - 2017

Year	Total Trucks	Trucks with Lift Axles (4-, 5-, 6-, 7-Axles)	Percentage of Total Trucks
2006	11,504	6,926	60%
2007	16,926	10,921	65%
2010	12,986	8,614	62%
2011	15,205	10,303	66%
2012	12,512	8,908	71%
2013	10,729	7,954	74%
2014	15,450	11,300	72%
2015	16,275	11,297	68%
2016	15,113	10,214	68%
2017	16,486	12,363	74%

The table above shows the following trend regarding total number of ready mix trucks. The numbers significantly decrease between the period of 2007 – 2011 and then decrease again to an all-time low in 2013. This may have been due to the recession period of 2007 – 2011. The author also checked the NRMCA surveys to see if the average load size (in cubic yards) changed over the years as well. The survey results showed that the average load carried by ready mix trucks stayed relatively constant around 8.0 cubic yards through the entire 2006 – 2017 time period. Next, to determine if a certain configuration was contributing significantly to this growing trend of the proportion of ready mix trucks with lift axles, the author separated the different configurations. Table 5-4 and Figure 5-2 show the results.

Table 5-4. NRMCA Survey – Proportion of Axle Configurations 2006 – 2017

Year	Total Trucks	4-Axle / Booster	%	4-Axle / Pusher	%	5-Axle	%	6-Axle	%	7-Axle	%
2006	11,504	3,581	**31%**	896	**8%**	1,769	**15%**	650	**6%**	30	**0%**
2007	16,926	4,039	**35%**	1,398	**12%**	3,510	**31%**	1,891	**16%**	83	**1%**
2010	12,986	3,421	**30%**	1,996	**17%**	1,598	**14%**	1,294	**11%**	305	**3%**
2011	15,205	4,676	**41%**	1,847	**16%**	2,436	**21%**	1,047	**9%**	297	**3%**
2012	12,512	3,266	**28%**	1,851	**16%**	2,359	**21%**	1,151	**10%**	281	**2%**
2013	10,729	3,500	**30%**	1,691	**15%**	1,616	**14%**	1,115	**10%**	32	**0%**
2014	15,450	4,121	**36%**	2,335	**20%**	2,539	**22%**	1,959	**17%**	346	**3%**
2015	16,275	5,897	**51%**	1,853	**16%**	2,729	**24%**	1,462	**13%**	356	**3%**
2016	15,113	4,616	**40%**	1,070	**9%**	2,583	**22%**	1,560	**14%**	385	**3%**
2017	16,486	5,276	**46%**	770	**7%**	3,639	**32%**	2,261	**20%**	417	**4%**

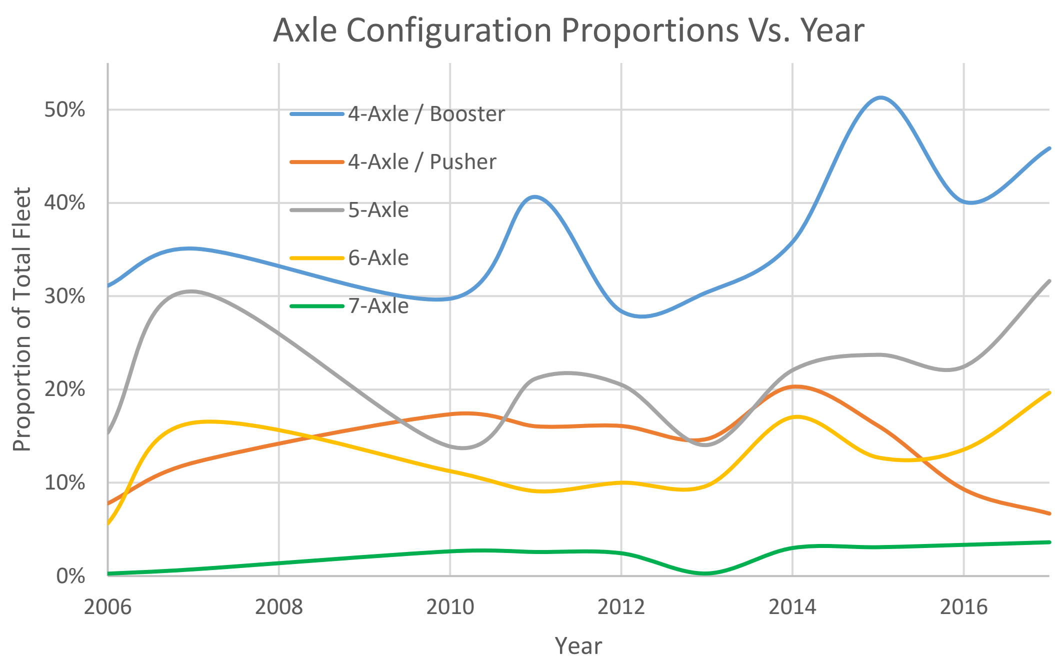


Figure 5-2. NRMCA Survey - Proportion of Configurations Over the Years

As can be seen in the table and figure, there does appear to be an upward trend in the proportion of all configurations of ready mix trucks except the "4-Axle / Pusher". Compared to the percentage near the beginning of the analysis period, the largest growths have been in configurations with 5 or more axles. These growth rates (averaged over the 12 years of survey data analyzed) are shown in Table 5-5 below.

Table 5-5. NRMCA Survey – Growth Trend of Axle Configurations 2006 – 2017

Configuration	Annual Growth Rate (%)
4-Axle / Booster	1.23%
4-Axle / Pusher	-0.09%
5-Axle	1.35%
6-Axle	1.17%
7-Axle	0.28%

The survey also asked respondents to report the average annual mileage for vehicles. The results of that question over the years is shown below in Table 5-6.

Table 5-6. NRMCA Survey – Growth Trend of Axle Configurations 2006 – 2017

Year	Average Annual Miles / Truck	Median
2006	18,896	17,408
2007	17,976	16,451
2008	17,755	14,543
2010	13,801	12,838
2011	13,860	13,716
2012	14,925	14,065
2013	14,773	13,400
2014	16,435	14,969
2015	15,796	14,262
2016	16,201	15,820
2017	16,419	15,260

As can be seen in the table above, at the beginning of the analysis period, the central tendency of the average annual miles was around 18,000 miles. Then, over the next five years, the annual average mileage decreased to around 14,000 miles, before increasing again and stabilizing around 16,000 miles.

The following section discusses an author-administered survey for the ready mix industry and presents the results.

5.2 Ready Mix Industry Survey on Lift Axles

The author developed a survey for ready mix industry representatives, including truck drivers or administrative employees at ready mix companies. The survey instrument was reviewed and was given an Institutional Review Board (IRB) approval by the Office of Research Support and Compliance at the University of Texas at Austin. This survey can be found in Appendix C.

The survey contains 10 questions regarding lift axle usage, including the company's fleet composition, trucks with fixed axles only and trucks with lift axles, reasoning for presence or absence of trucks with lift axles, geographic area of operations, SHV safety considerations, and SHV cost inquiries. Respondents were encouraged to only share as much information as they felt comfortable, and the survey was developed in such a way that it could be answered fully anonymously.

The author developed a list of companies to contact by searching through the NRMCA member directory, as well as the directories of each of Texas and its peer states' ready mix trade associations. From this methodology, a total of 523 companies were contacted either by email or by phone and requested to fill out the survey. Online trucking forums were utilized to distribute the survey further, but this method may have led to responses from outside of the ten peer states. Responses from outside the United States were discarded. To minimize the likelihood of repeat responses, i.e. multiple responses from the same company, the author used IP Address data and GPS data from the survey responses (given as an output from the Qualtrics survey system), to separate responses from one another. It is important to note that neither of these data points could identify individual responders. The survey was set up to prevent the same person from taking the survey twice. Although the GPS data cannot be used to uniquely identify responders (preserving anonymity), it was used as a rough estimation of uniqueness.

After cleaning up the responses and working to reduce the likelihood of multiple responses from the same company through GPS and IP address analysis, there were 249 responses remaining. Of these 249 responses, 160 (64%) of the companies operate SHVs currently, and 89 (36%) do not. Of the 89 companies that do not operate SHVs, 65 (73%) stated their companies intended to operate lift axles in the future. 26 (29%) gave specific reasons for not wanting lift axles such as increased operating costs. The following tables and figures summarize the results of the survey, with discussion.

Table 5-7. Location of responses (with NRMCA categories and 2017 comparison)

Region	Survey	NRMCA 2017
South-eastern	70 (28%)	23%
Eastern	45 (18%)	13%
Great Lakes / Midwest	51 (20%)	9%
South Central	73 (29%)	15%
Pacific Southwest	7 (3%)	20%
Other	3 (1%)	19%

The locations for the survey responses were organized into the same categories used in the NRMCA surveys. The ‘Other’ category includes the Pacific North-west, the Rocky Mountain and North Central Regions. Since the focus of this Thesis survey was not in the ‘Other’ category, the author spent less outreach efforts in those regions, leading to significantly fewer responses from there. Each of the other regions includes at least one state that is the focus of this Thesis. A point to be noted here is that there were some survey responses received from outside of the United States, but they were discarded in this summarization.

Table 5-8. For companies with no SHVs, reasons why not

Reasons to Not Operate SHVs (multiple selections allowed)	Survey
Increased Capital Costs	9 (35%)
Increased Operation / Maintenance	10 (38%)
Does Not Fit Company Plans Now	5 (19%)
Other	2 (8%)

The table above shows responses from companies who stated they do not currently implement SHVs, for the reasons selected above. Not all companies who do not implement SHVs elected to provide a reason, or state their intent to implement SHVs in the future (see Table 5-9). However, of the responses received, the highest proportion of responses stated that the reason for not operating SHVs was increased operation / maintenance costs. This agrees with comments from truckers, who said SHVs cost more to maintain, as they have the additional components including lift controls, air bags, the lift axle and tires. However, this increase in cost may be offset by increased financial gains from using lift axles.

Table 5-9. For companies with no SHVs but intent to implement, reasons why

Reasons to Intend SHV Operations (multiple selections allowed)	Survey
Flexibility in Operations	17 (30%)
Lower Operation Costs	20 (35%)
Maneuverability	9 (16%)
Increased Payload	30 (53%)
Interstate Allowance	20 (35%)

The table above shows responses from companies who stated they do not currently implement SHVs, but intend to implement them in the future, for the reasons selected above. As this was an optional question, not all companies intending to operate SHVs elected to provide reasons. However, of the responses received, the highest proportion stated that SHVs provide increased the payload. In addition, SHVs provide the ability to operate on interstate highways.

Table 5-10. Survey Responses about SHV safety

Are SHVs Safer?	Survey
No, Safety is largely driver dependent	142 (57%)
No, same level of safety	61 (24%)
Yes, due to more axles on the ground	25 (10%)
Yes, due to better braking	13 (5%)
Other	8 (3%)

The table above shows responses from all companies, regarding SHV safety, i.e. are SHVs comparatively more or less safe than trucks without lift axles. Of all the responses, the two answers which constituted roughly 80% of the answers were either a similar level of safety between lift and non-lift axle trucks, or that the safety of a truck largely depended on the operator.

Table 5-11. Survey Responses about SHV costs

Are SHVs Costlier?	Survey
Not Necessarily: Depends on Brand, Year, Condition	83 (33%)
Not Necessarily: Depends on Configuration	76 (31%)
Don't know	64 (26%)
No, we add lift axles after-purchase	5 (2%)
Yes, I have specific cost information	21 (8%)

The table above shows responses from all companies, regarding SHV costs, i.e. are SHVs comparatively more or less costly compared to trucks without lift axles. Most responses did not provide actionable data, including answers of “it depends” or “I don’t know”. However, some responders offered detailed information in a separate note on the survey. Although these costs varied, and the anonymous nature of the responses makes it hard to determine precisely which area of the US the response was regarding, the average percentage increase offered by responders was ready mix trucks with lift axles cost roughly 10% more to purchase and maintain than their non-lift axle counterparts.

Table 5-12. For companies with SHVs, trend of SHV numbers over three years

SHV growth trends over 3 years	Survey
0 - 15% growth	72 (45%)
15 - 30% growth	44 (28%)
Over 30% growth	33 (21%)
Negative (i.e. decline)	11 (7%)

Companies with SHVs were asked about their fleet numbers (SHV and total trucks) for the past three years, to develop a trend line for whether SHV numbers are generally increasing or decreasing. The table above shows the growth trends determined from the responses. The rates stated above are total growth rates over a period of three years of growth (2016-2019), not annual rates. 93% of the responders had increasing SHV growth rates, with the majority being under 15%. This result seems to indicate an overall growing trend for SHVs in the ready mix industry in the US.

Table 5-13. For companies with SHVs, average mileage of SHV trucks

SHV average annual truck mileage	Survey
5,000 to 9,999 miles	46 (29%)
10,000 to 14,999 miles	65 (41%)
15,000 to 19,999 miles	18 (11%)
20,000 to 29,999 miles	26 (16%)
Over 30,000 miles	5 (3%)

For companies operating SHVs, the survey requested average annual mileage for the SHV vehicles. The results are shown above, and the data from 160 responses had a mean of 12,688 miles and a median of 10,000 miles.

Table 5-14. Number of Companies stating reasons for choosing to operate SHVs

Reasons for SHV Operations (multiple selections allowed)	Survey
Flexibility in Operations	62 (39%)
Lower Operation Costs	68 (43%)
Maneuverability	38 (24%)
Increased Payload	78 (49%)
Interstate Allowance	50 (31%)
Safer	25 (16%)

The table above shows responses from companies with SHVs. Not all companies provided a reason why they elected to operate SHVs. However, the responses received provided a similar picture to that from companies without SHVs, i.e. the highest proportion of responses stated the benefits they'd receive with SHVs is the ability to increase the payload carried. Interestingly, although increased safety was an option for this question to all responders, only those from SHV-operating companies selected it as a reason. This may imply the presence of perceivable safety benefits to users. Otherwise, the results were similar to those from non-SHV-operating companies.

Table 5-15. For companies with SHVs, survey responses about SHV training

Does your company provide SHV training to drivers?	Survey
Yes	129 (81%)
No	16 (10%)
Other	15 (9%)

Of the companies that operate SHVs, an overwhelming majority of them provide SHV training to drivers. Some of the 'Other' responses provided details, most of which said their companies do not have a separate training for SHVs, but drivers are constantly reminded to remain alert to the fact that they are driving significantly longer trucks (the author interpreted responses like these to refer to the additional length that is provided when a booster axle is deployed, and to the fact that the truck chassis would also need to be longer to accommodate lift axles, especially for SU 5, SU 6 and SU 7 units.

Overall, the survey responses seem to agree with the results of the NRMCA survey analysis, with some differences. For example, the 2017 average for annual mileage was 16,419 miles from the NRMCA survey, but 12,688 miles from this survey. It should be noted here that the NRMCA results include all ready mix trucks, not separated by SHV operating companies. Therefore, the average annual mileage for ready mix trucks from the NRMCA survey and this survey are not drawn from the same sample. Also, there was a two-year time gap between the NRMCA survey and this one, 2017 and 2019.

5.3 Industry Insights from Online Forum

One significant avenue of survey distribution was an online forum for truckers that has over 20,000 active members as of July 2019 (Reddit, 2019). Forum members were asked to take the survey, but some responders on the forum also volunteered helpful insights. However, many of these responders discussed lift axles in general, not necessarily in the ready mix industry. Some noteworthy observations and opinions are provided in the following summary from forum interactions with fifteen truckers:

- When asked for the main advantage of using lift axles, the majority (four) mentioned the increased weight-carrying capacity allowed by lift axles. The next most commonly cited reason (three responses) was to avoid being ticketed on highways, i.e., remaining in compliance with the law. Two individuals responded that lift axles reduce tire wear because of the ability to raise axles when not in use. One responder mentioned how raising these axles when empty also allowed him / her to save on toll charges (in an area where charges are per axle), while another response mentioned the possibility of reducing fuel consumption, due to having less rolling resistance when the axle is raised.

- Following from the conversation about reduced fuel consumption or tire wear, one commenter expanded on the topic: “Every time the truck is turning, even only on a slight curve, those axles are put into a bind creating more friction and tire wear. Lifting one of those axles eliminates that bind. Since trucks are driven tens of thousands of miles yearly the savings from utilizing drop or lift axles adds up pretty quick”. Another commenter added that, in his experience, improvements to fuel mileage are considered worthwhile if they make differences of even a tenth of a mpg. The NRMCA survey results showed that ready mix trucks only get about 3 to 3.5 miles per gallon compared to long haul trucks which range from 6 to 8 mpg depending on the age of the truck and configuration, further adding to the importance of improvements in fuel efficiency.
- One responder working in the ready mix industry mentioned how his / her company is in the process of slowly replacing the fleet with trucks that all have pusher and booster axle trucks. When asked how long the replacement process will take, the responder said: “I couldn't tell you exactly how long it will take. I just know they get a few trucks a year. Example: last year we got about 15 five-axle lift axle trucks and retired 7 three-axle trucks (without lift axles).” The truck configuration for these new trucks is 1S-1L-2-1B.

- That responder also mentioned that training specific to lift axle usage was brief, and mainly covered how to operate the lift mechanism. Drivers were also taught to be aware of obstructions within the area 10 feet behind the truck (in instances of the presence of a booster axle).

5.4 Insights From UT-CTR SHV Project

As part of the UT-CTR project, the author's team interviewed personnel from the Texas Department of Motor Vehicles (TxDMV) and Texas Department of Public Safety (DPS), to gain insight on those two departments' views on SHVs.

From an interview with the Director of DPS Commercial Vehicle Enforcement Division, the research team learned more about the organization's views on SHVs. More specifically, at the time of the interview in late 2015, the DPS was not specifically concerned about problems with SHV safety or overweight issues, and procedurally treated them similar to any other commercial vehicle. After this interview, the Director provided the team with DPS roadside weight enforcement data.

From two interviews with Texas DMV personnel, the team learned that TxDMV does not record lift axle data during truck registration and registers trucks based on truck operational type and GVW. The number of axles is not recorded since there is no requirement in state laws to include number of axles in registration data. After these interviews, the Director of the Vehicle Titles and Registration department of TxDMV provided the team with truck registration data.

The next chapter provides a discussion of the results presented here, including highlights of the Thesis research, possible interpretations, and perspectives learned. It finishes with concluding remarks, as well as some recommendations for future research.

Chapter 6: Conclusion

The main objective of this research was to document current ready mix SHV operations and laws and to research the reasons that ready mix companies might choose to operate SHVs. This was accomplished through a literature review, surveys with State Officials regarding truck size and weight laws that affect SHVs, ready mix truck sales data, a survey with 249 ready mix truck companies and additional information learned through an online trucking industry forum. This information was used to evaluate perceived benefits including safety considerations, reductions in equipment wear and maintenance costs, ability to operate on the Interstate Highway system and increased payload capacity.

Overall, all methods of study indicated an upward trend in lift axle usage on ready mix trucks. The NRMCA data showed an SHV proportion in the ready mix industry of approximately 60-70% from 2006. The survey administered by the author also corroborated this, with 64% of the responses from companies that operate SHVs. However, SHVs in general are relatively rare, e.g. in UT-CTR's SHV study, percentage of SHVs among certain industries in Texas was around 17%, while percentage of SHVs among all trucks was around 2%. These percentages varied by location, industry, and data collection method. The large difference between the survey results and the UT-CTR SHV study could be due to the fact that the UT-CTR study focused only on Texas, whereas the NRMCA surveys included the entire United States as well as the fact that the UT-CTR study included non-ready mix industries. The author's Thesis considered 6 of the 8 regions contained in the NRMCA study. However, the author believes specifically analyzing the proportion of SHVs in the ready mix industry in Texas is worthwhile.

Potential future research in this area were identified during the study and includes observations by truckers the author interacted with. One possible study relates to the claim that SHVs help with fuel economy, which has been studied previously for lift axles on combination trucks (Surcel & Bonsi, 2015). Further research about ready mix truck safety based on steering and braking efficiency. This could be explored using the Texas Crash Record Information System (CRIS) and the Fatality and Analysis Reporting System (FARS). This proposed study would evaluate crash data, including numbers of SHVs and non-SHVs involved in crashes, crash contributing factors, crash severity, and relationships between crash locations and road geometry. Another potential avenue of research in the area of safety was determined after analyzing stopping distances and criteria in Chapter 2 of this Thesis. The author found that there was a disparity in the way braking parameters were defined and measured between NHTSA, CFR, transportation crash analysts, transportation agencies, and transportation researchers. A possible avenue of research is to create a framework to bridge the differences and develop a common language between these groups, to allow deeper understanding of issues concerning truck braking and safety. Additional research topics include estimating the potential cost savings realized by operating SHVs including reduced fines for overloaded axles and reduced tolls on per-axle toll roads.

Overall, the objectives set out at the beginning of this Thesis were to collect data on and interpret trends in ready mix fleet distributions and SHV numbers in the ready mix industry (Chapter 3, Chapter 5); analyze differences in state regulations regarding SHVs (Chapter 4); and determine factors that influence a ready mix company's decision to operate SHVs (Chapter 5). The different chapters of this thesis stated the results of research efforts aimed at achieving the objectives, while this concluding chapter set some areas for future research.

Appendices

Appendix A – Lift Axle Regulation Survey

Thank you for taking the time to fill out this survey. What follows is a brief description.

Background

Federal Highway Administration has recently increased focus on Specialized Hauling Vehicles (SHVs). For the purposes of this survey, SHVs are defined as single-unit trucks that have liftable and/or booster axles. Many research studies are being implemented which look at how vehicles with liftable axles operations affect infrastructure. However, this survey is **NOT** part of those projects. The focus of this survey is **NOT** to analyze the infrastructure effects, but to understand differences in regulations regarding liftable axles across the US.

The type of trucks this survey is regarding: A **single-unit** truck with from 4 to 7 axles, out of which 1 to 4 axles are liftable and can be raised once the cargo is delivered. Some pictures are provided below for further clarification.

Please fill out this survey as accurately and completely as possible. If you need help or have questions about filling out this form, please contact **Manar Hasan (Graduate Research Assistant at the University of Texas at Austin)** at **manar.hasan@utexas.edu** or **(512) 887-3563.**

The survey is expected to take approximately **5-10 minutes** to complete. Thank you again for your time.

The following are examples of different types of trucks with liftable axles. For example, a truck is referred to as an 'SU6' if it has 6 axles in total, with ANY of them being liftable, regardless of where and how many are liftable.

The following are examples of different types of trucks with liftable axles. For example, a truck is referred to as an 'SU6' if it has 6 axles in total, with ANY of them being liftable, regardless of where and how many are liftable.

SU4 with one pusher axle

SU4 with one tag axle

SU5 with one pusher and one booster axles

SU6 with one pusher and one tag axles

SU7 with three pusher and one booster axles

SU7 with four pusher axles

State?

1. Does your state comply with the Federal Mandated Federal Bridge Formula B (FBF-B) on your **interstates**?

Yes

No

Comments, if any:

2. Does your state comply with the Federal Mandated Federal Bridge Formula B (FBF-B) on **other highways** in your state?

Yes

No

If not, please briefly explain the max gross weight for those other highways?

3. Do your state's weigh stations have special procedures to weigh lift axle vehicles?

- Yes, they are treated differently from traditional trucks
- No
- Unsure

If different, please specify how:

4. Does your state keep records of the number of trucks with liftable axles?

- Yes, this information is recorded when taking weights, e.g. at weight stations
- Yes, this information is recorded during truck licensing/registration
- No
- Unsure

Comments, if any:

5. Does your state have specific regulations regarding lift axle vehicles?

- Yes
- No
- Unsure

Comments, if any:

6. If yes, which type of regulations are in place?

- Permit/Approval required for usage
- Lift axles are required to meet Federal regulations regarding fixed axles
- Usage allowed based on specific axle configuration
- Lift axle controls are regulated (where controls are located, how much control the driver has in-trip, etc.)

Comments, if any:

7. Does your state have specific lift axle **steering/equipment** specifications? (e.g. must be self-steering, etc.)

- Yes
- No
- Unsure

If yes, please specify:

8. Does your state have specific lift axle **configuration** specifications?

- Yes
- No
- Unsure

If yes, please specify:

9. Does your state have specific lift axle **control system** specifications?

- The lift axle weight/pressure controls must be outside the reach of the driver, but the up-and-down controls may be within reach of driver.
- Both lift axle weight/pressure controls and up-and-down controls must be outside reach of driver.
- Both lift axle weight/pressure controls and up-and-down controls may be within reach of driver.
- There are no current specifications for lift axle control systems

Comments, if any:

10. Does your state have specific procedures for inspecting vehicles with lift axles?

- Yes
- No
- Unsure

If yes, please specify:

11. Which industries do you mostly see lift axle trucks in (in your state)?

- Agricultural Products
- Crane
- Hot Mix Asphalt Concrete
- Dump Trucking (e.g. gravel, sand, top soil, etc.)
- Garbage / Recycling
- Ready Mix Concrete
- Oil
- Other

If other, please specify:

12. Which types of roads do you see lift axle trucks on mostly?

- Interstate Highways
- Other Highways
- Local Roads/Arterials
- Other/Unsure

Comments, if any:

13. Which areas do you see lift axle trucks in mostly?

- Metropolitan areas
- Other specific area
- No specific area of concentration

If other, please specify:

14. Are there any research projects or plans to do research regarding trucks with liftable axles in your state?

- Yes, already finished
- Yes, currently researching
- Yes, planned in the future
- No
- Unsure

Comments, if any:

15. What types of lift axle trucks are being used in your state? Please briefly explain truck configuration and load being carried.

16. Thank you for your invaluable responses. If you have any additional comments or questions, please feel free to write them here.

17. Filling out the table below is OPTIONAL. Please fill out if you are interested in receiving results of the survey, or if you're willing to answer more questions that may come up in research.

Name	
Phone Number	
Email Address	
Would you be willing to answer more questions?	
Would you like to receive results of survey?	

Thank you very much for taking the time to complete the survey. Your response has been recorded.

If you have any questions, please contact Manar Hasan at manar.hasan@utexas.edu or (512) 887-3563 (email preferred).

APPENDIX B – CONTACTS FOR LIFT AXLE REGULATION SURVEY

State	Person Name	Position	Entity
California	Mike Hamilton	Officer	California Highway Patrol
Florida	Anonymous		Florida Highway Patrol
Georgia	Johnny Jones	Major	Georgia Department of Public Safety
Illinois	Brian Cluever	Executive Director	Illinois Truck Enforcement Association
Michigan	Anonymous		Michigan State Police
New York	Anonymous		New York State Police
North Carolina	Kenneth Snead	Sergeant	North Carolina State Highway Patrol
Ohio	Tom (Unknown Last Name)		Public Utilities Commission of Ohio Compliance Division
Pennsylvania	Greg Fischer	Motor Carrier Enforcement Specialist	Highway Patrol CVSD
Texas	Joshua Alcala	Sergeant	Texas Department of Public Safety CVE

APPENDIX C – READY MIX LIFT AXLE SURVEY

Thank you for taking the time to fill out this survey. What follows is a brief description.

Background

Federal Highway Administration has recently increased focus on Specialized Hauling Vehicles (SHVs) by requiring each state to examine the statewide SHV fleet makeup. This requirement includes SHV numbers and types, axle configurations and whether these configurations are currently considered in the American Association of State Highway and Transportation Officials (AASHTO) Manual for Bridge Evaluation.

For the purposes of this survey, SHVs are defined as single-unit trucks that have lift axles. Various research studies are looking at how SHV operations affect infrastructure. However, this survey is **NOT** part of those projects. The focus of this survey is **NOT** to analyze the infrastructure effects of SHVs, but to understand why **companies** choose to implement SHVs. This survey is limited to the **Ready Mix** industry. More specifically, this survey is limited to **ready mix trucks including drum and volumetric mixers**.

Specialized Hauling Vehicles (SHV) as defined in the survey – A **single-unit** truck with 4 to 7 axles, out of which 1 to 4 axles are **lift or booster axles** and can be raised once the cargo is delivered. Some pictures are provided below for further clarification.

Please fill out this survey as accurately and completely as possible. If you need help or have questions about filling out this form, please email **Manar Hasan (Graduate Research Assistant at the University of Texas at Austin)** at **manar.hasan@utexas.edu** or call/text him at **(512) 887-3563.**

All identifiable information in survey responses will be kept confidential, and the information obtained from the survey will be amalgamated.

The survey is expected to take **less than 5 minutes** to complete. Thank you again for your time.

The following are examples of different types of SHVs in the Ready Mix Industry. For example, a truck is referred to as an 'SU6' if it has 6 axles in total, with ANY of them being lift axles, regardless of where and how many are lift axles. Therefore, the following trucks are: SU4, SU5, SU6, SU7, SU6, and SU4, with the lift axles in different positions.

The survey begins on the next page.

1. Approximately how many ready mix trucks are in your fleet?

2. How many SHVs (ready mix trucks with lift axles) does your ready mix fleet currently have?

If # of SHV answer is 0, the following questions are shown:

3. If your company has no such trucks with lift axles, are any of the following statements true? (Select all that apply)

- My company has given a specific reason for not implementing SHVs
- My company has stated its intention to start using SHVs in the near future

3.a. What reason did your company state for not implementing SHVs? (Select all that apply)

- Our company doesn't need them at this time
- Increased Capital Costs (Trucks Cost Too Much)
- Increased Operating/Maintenance Costs
- Other

3.b. What reason, if any, did your company provide for starting to use SHVs in the future? (Select all that apply)

- SHVs allow company to run trucks legal on interstate highways (or the like)
- SHVs allow company to increase payload on trucks
- SHVs have lower operating costs
- SHVs are easier to maneuver
- SHVs allow company to have larger flexibility in operations
- SHVs are safer to operate
- SHVs provide some insurance against receiving overweight tickets
- Other

4. In which general geographic area do your trucks mainly operate? (Be only as descriptive as you are comfortable with, e.g. New York | Hamilton County in Northern NY | In/Around the town of Long Lake, NY - all are acceptable levels of detail. However, please include the State in your response, if you can)

5. Do you think an SHV is 'safer' (fewer accidents) than a 3-axle ready mix truck?

- No, both types of trucks provide about the same level of safety
- No, safety really depends on the driver - not the truck
- Yes, when all axles are on the ground. No, when some axles have to be lifted when making a turn.
- Yes, SHVs have better braking, since there are more tires on the ground.
- Other

6. How much more does an SHV ready mix truck cost to purchase, compared to a 3-axle truck?

- About the same to buy the basic truck, we add the axles and control units later in our own shop.
- It depends on the configuration and how many axles we are adding.
- I know specifics about how much more an SHV costs to purchase, and I can share these details in the next question. An SHV costs about ____% more, because the basic truck chassis has to be longer and brakes upgraded. From that point, it costs about ____ for each additional lift axle and _____ for the booster axle.
- Depends on the brand of truck, which year and how many trucks we are buying.
- Don't know.

6.b. Could you provide some more details, especially if you are able to provide specific cost information?

7. Filling out the table below is OPTIONAL. Please fill out if you are interested in receiving results of the survey, or if you're willing to answer more questions that may come up in research. Please note that results will not include names of companies/people that responded to survey.

Name of Trucking Company (Doing Business As Name)	
Name of Contact Person	
Phone Number	
Contact Email Address	
Would you be willing to answer more questions?	
Would you like to receive results of survey?	

8. Thank you for your invaluable responses. In an effort to keep the survey short, we may have missed something. If you would like to add any additional comments or questions, please feel free to write them here. Afterwards, proceed to the next question to officially have your survey responses recorded.

Thank you very much for taking the time to complete the survey. Your response has been recorded.

If you have any questions, please contact Manar Hasan at manar.hasan@utexas.edu or (512) 887-3563 (email preferred).

If # of SHV answer is a number not equal to 0, the following questions are shown:

3. To provide an idea of if SHV usage in your company is trending up or down, could you say roughly how many SHV ready mix trucks were operated in the following years:

	SHVs Only	Total Ready Mix Truck Fleet
2016		
2017		
2018		
2019		

4. In which general geographic area do your SHVs mainly operate? (Be only as descriptive as you are comfortable with, e.g. New York | Hamilton County in Northern NY | In/Around the town of Long Lake, NY - all are acceptable levels of detail. However, please include the State in your response, if you can))

5. What is the average annual distance travelled by your Ready Mix trucks? (For example, on average, an SHV truck in your company may travel "15,000" miles per year - please specify unit)

	SHVs	Non-SHV Trucks (if applicable)
Average Annual Distance		

6. We've heard several reasons a company might prefer to implement SHVs in their fleet. Do you know why your company implements them? (Select all that apply)

- SHVs allow company to run trucks legal on interstate highways (or the like)
- SHVs allow company to increase payload on trucks
- SHVs have lower operating costs
- SHVs are easier to maneuver
- SHVs allow company to have larger flexibility in operations
- SHVs are safer to operate
- SHVs provide some insurance against receiving overweight tickets
- Other

7. Do you think an SHV is 'safer' (fewer accidents) than a 3-axle ready mix truck?

- No, both types of trucks provide about the same level of safety
- No, safety really depends on the driver - not the truck
- Yes, when all axles are on the ground. No, when some axles have to be lifted when making a turn.
- Yes, SHVs have better braking, since there are more tires on the ground.
- Other

8. How much more does an SHV ready mix truck cost to purchase, compared to a 3-axle truck?

About the same to buy the basic truck, we add the axles and control units later in our own shop.

It depends on the configuration and how many axles we are adding.

I know specifics about how much more an SHV costs to purchase, and I can share these details in the next question. An SHV costs about ____% more, because the basic truck chassis has to be longer and brakes upgraded. From that point, it costs about ____ for each additional lift axle and _____ for the booster axle.

Depends on the brand of truck, which year and how many trucks we are buying.

Don't know.

8.b. Could you provide some more details, especially if you are able to provide specific cost information?

9. Does your company provide special training for drivers of SHVs?

Yes

No

Other

10. Filling out the table below is OPTIONAL. Please fill out if you are interested in receiving results of the survey, or if you're willing to answer more questions that may come up in research. Please note that results will not include names of companies/people that responded to survey.

Name of Trucking Company (Doing Business As Name)	
Name of Contact Person	
Phone Number	
Contact Email Address	
Would you be willing to answer more questions?	
Would you like to receive results of survey?	

11. Thank you for your invaluable responses. In an effort to keep the survey short, we may have missed something. If you would like to add any additional comments or questions, please feel free to write them here. Afterwards, proceed to the next question to officially have your survey responses recorded.

Appendix D – Post on Online Trucking Forums Requesting Participation in Thesis Research

I'm a Transportation Engineering student researcher at the University of Texas at Austin, and I wanted to see if you could assist me in some research I'm doing. I posted about this a couple of years ago (see post here), but I'm starting this research back up (after a significant pause) with some changes. The one-liner for my research (which has a more refined scope now) is that I'm researching how / why companies in the ready mix industry use lift axles (or not).

There's a lot of recent research being done about trucks like with lift axles, but few, if any, focus on learning from the actual end-user of these trucks: the truckers / trucking companies. My master's thesis focus is on asking questions directly to truckers / trucking companies to learn from their perspective.

For this research, I'm trying to understand things like how a ready mix company might benefit from lift axles, what are the primary motivations, how drivers are specifically trained to use them (if they are), do they cost more than regular trucks, etc. Please consider helping out even if you drive a truck without lift axles, since it's important for me to learn about why not. I'm looking to learn as much as I can about ready mix operations with / without lift axles. For easy distribution, I have a survey made, and it takes less than 5 minutes to complete. Here is the link to the survey, which can be answered completely anonymously (if you wish):
http://bit.ly/ReadyMixLiftSurvey

If you'd also be willing to connect with me in depth about this, comment and I can ask specific questions (or private message). I'd also be happy to answer questions you may have about my research. Or just any general helpful comments about lift axles in ready mix trucking would be greatly appreciated.

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Vita

Manar Hasan was born in College Station, Texas in 1992. He moved to Dhaka, Bangladesh in 1995, then to Oxford, Mississippi in 2001, then back to Dhaka, Bangladesh in 2004, and finally to Austin, Texas in 2009. After finishing high school in Austin, he started his pursuit of a Bachelor's in Civil Engineering at the Cockrell School of Engineering at The University of Texas at Austin. He graduated in 2015, and immediately returned to pursue a Master's degree in Transportation Engineering under Dr. C. Michael Walton.

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